OUTLINE OF EXPERIMENTS

AND

DESCRIPTION OF APPARATUS AND MATERIAL

SUITABLE FOR

ILLUSTRATING ELEMENTARY INSTRUCTION

IN

SOUND, LIGHT, HEAT, MAGNETISM, AND ELECTRICITY.

PREPARED BY

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LONDON:
PRINTED BY GEORGE E. EYRE AND WILLIAM SPOTTISWOODE,
PRINTERS TO THE QUEEN'S MOST EXCELLENT MAJESTY.
AND SOLD AT THE SOUTH KENSINGTON MUSEUM,
AND BY CHAPMAN & HALL,
AGENTS TO THE DEPARTMENT FOR THE SALE OF EXAMPLES,
193, PICCADILLY, LONDON.
1881.

Price Threepence.

ELEMENTARY EXPERIMENTS IN SUBJECT VIII.

I.—SOUND AND WAVES.

N.B.— *The numbers in brackets in this list refer to the paragraphs of the list of apparatus and material;* S. A. *signifying sound apparatus, p.* 10.

WAVES.

Transmission and Reflexion of Transverse Motion in Elastic Cords.

1. An empty vulcanized caoutchouc tube 12 feet long is fastened to the ceiling at one end, and is held at the other in the hand in a nearly vertical position. Strike it with the other hand. A half wave travels along and comes back reversed (S. A. 1).

2. Two similar tubes, equally stretched, are similarly and simultaneously struck; rate of motion of displacement is the same (S. A. 1).

3. Stretch one more than the other, keeping each at its full length, Compare time of wave from end to end. Compare rate of wave by making the unequally stretched strings of equal length (S. A. 1).

4. Fasten one empty and the sand-filled tube side by side. Stretch equally and take equal lengths. Compare rates of wave motion. Stretch sand-filled tube till the rates are equal, taking equal lengths (S. A. 1).

5. Fasten an empty and the sand-filled tube end to end and fasten the end of one to the wall. Send a half wave up the other. Notice change of rate and change of amplitude when the half wave passes from one to the other; also after reflexion (S. A. 1).

6. Make the half wave with either of the tubes longer and longer by shaking the end more slowly until the front of the reflected half wave meets the front of the next advancing half wave in the middle of the tube. Formation of node in the middle. Wave length equal to length of tube. Formation of one complete stationary wave. With half rate of excitement the tube swings as a whole, and the wave length is double the length of the tube. By quicker motion break up the tube into segments separated by nodes. Repeat with differently stretched and loaded tube (S. A. 1).

Transmission and Reflexion of Transverse Motion in Liquids. Water-Waves.

7. Examine motion of water in trough (S. A. 2). Fill trough nearly full of water, place chips of cork along edge of water, depress and elevate block (S. A. 2) at one end of trough and watch the motion of the floating cork chips. Substitute little beeswax balls mixed with iron filings till they just float and place them at various depths. Observe the closed curves in which the balls move.

8. Take the two circular zinc troughs (S. A. 3). Nearly fill with water. Set the water swinging (oscillating) in various ways in both troughs (*a*) by tilting them, producing a nodal line in the middle, (*b*) by moving up and down in the centre some light circular body, such as an empty beaker (S. A. 3). Show, by counting with a watch, that the number of times the water returns to a given position in a given time is greater in the smaller trough, and that the two numbers are inversely as the square roots of the troughs' radii or diameters. Show, by hanging a bullet from a thread (S. A. 3), having the length

of the trough's radius that the water motion in case (*b*) is at the same rate as the pendulum with both troughs. Examine the motion of the water in case (*b*), and show that a nodal ring is formed nearly at one-third of the radius from the circumference, and that the vertical motion at the centre is nearly double that at the circumference. As the wave's path is from the centre to the circumference and back, show that the rate of wave progression is directly proportional to the square root of the wave length.

Air Motion in Mass.

Vortex Rings.

9. Fill case (S. A. 4) with smoke or chloride of ammonium in suspension. Hit the canvas at the back, and examine the motion general and internal of the vortex rings. Blow out a candle 20 feet off. Send one ring to overtake another, and notice rigidity.

Partial Vacuum on Dispersion.

10. Balance the piece of pasteboard (5*a*) on the point of the finger; place the disc with the tube over it, and blow through the tube. Notice that the discs adhere together, showing that the dispersion of the air column in the tube when it meets the lower disc and passes between the two is rarefied.

Approach caused by Vibration.

11. Float a toy air ball (S. A. 6) on clear water, and show that when a tuning fork which has been struck is brought near it the ball approaches the fork.

Connexion between the Volume and Density and the Pressure on or Tension of a Gas.

12. Mercury is poured into the open end of the tube (S. A. 7) just in sufficient quantity to cover the bottom of the bend. The air in the shorter limb is then exactly at the atmospheric pressure. Any quantity of mercury is then poured in, and the difference in height between the two columns is measured. The pressure to which the gas is now subjected is the atmospheric pressure (for which the barometer is consulted) plus the pressure of the difference of the mercurial columns. The volume of the air, which may be considered as the length of the air column in the shorter limb, is found to be in all cases inversely proportional to the pressure.

Heat liberated on the Compression and absorbed on the Expansion of Air.

13. Fasten German tinder to the bottom of the wooden rod in (S. A. 8) and, placing the closed end of the tube on the table, thrust the wooden rod down. After one or two thrusts the tinder will light. Put a drop of bisulphide of carbon on a pellet of cotton wool and roll it in and out of the tube, then thrust the rod down, the bisulphide will flash. Clean the tube and place in it a pellet of cotton wool moistened with water; push the rod down to about a quarter the length of the tube from the bottom. After a time pull it up suddenly. Clouds of condensed watery vapour will be formed.

Propagation of Compression and Rarefaction through Solids and Liquids.

14. Arrange "solitaire" balls or marbles (S. A. 9) in a groove, and hit the row with one, two, or three, noticing the number which are sent off from the other end.

15. Strike tuning fork (S. A. 6) and hold its root on one end of a deal rod (S. A. 6), and place a board (S. A. 6) on and off the other end. This shows that the waves of compression and rarefaction travel along the rod.

16. Fasten one end of the sand-filled tube (S. A. 1) to the ceiling. Fasten a piece of paper near the top. Send a wave of rarefaction up the tube by quickly pulling the free end.

17. Fill tube (S. A. 11) with water. Strike fork armed with cork cone (S. A. 11), and plunge cone into water at top of tube. The sound heard shows the wave of compression travels through the water.

Sound Waves.

Propagation and Reflexion of States of Compression and Rarefaction through Air.

18. The tubes (S. A. 12) are fitted end to end. A watch is placed at such a distance from the ear as to be inaudible. The tube is placed over the ear and directed towards the watch. The ticking becomes audible.

19. The tubes (S. A. 12) are supported horizontally at an angle of 90° with one another. A watch is placed at the end of one, and the ear at the end of the other (the ends furthest apart), and screens are placed between the ear and the watch till the latter becomes inaudible. A piece of cardboard or the hand or a flat flame is placed at their contiguous ends, making 45° with each tube. This makes the watch audible and proves the law of reflexion.

Destruction of Sound Waves.

20. The tubes (S. A. 12) are arranged horizontally end to end with an interval of half an inch between. The watch is placed at one end of one tube, the ear at the other end of the other tube, at such distances that the watch is faintly audible. A dry cloth placed between the tubes does not destroy the sound, a wet one does; so does a current of heated air from a flame.

21. A watch is loosely wrapped in folds of flannel till it is inaudible. A deal rod with board attached (S. A. 13) is thrust amongst the flannel till it touches the watch, which then becomes audible.

22. A hand bell is heated over an air gas burner. At a certain temperature it ceases to ring when struck.

23. A glass funnel (S. A. 15) is stopped at its neck and partly filled with a solution of carbonate of sodium. When struck it rings. Add a solution of tartaric acid; the effervescence causes a dullness in the sound.

Refraction of Sound.

24. A toy air-ball (S. A. 6) is filled with carbonic acid. This is made by putting some marble into the flask (S. A. 16), putting in the cork, and then pouring water and hydrochloric acid down the straight tube. The air-ball is emptied of air and tied over the end of the bent tube. When filled it is tied off, and hung between the watch and the ear. The watch being two or three feet off and the ball close to the ear, the loudness of the watch's ticking is increased.

Formation of Notes.

25. The humming top (S. A. 17) is spun on a hard surface. A card is held against the toothed wheel. A note is produced, which becomes lower in pitch as the top moves slower. Air is blown through the tube (S. A. 17) on to the outer and on to the inner ring of holes. The note produced by the former is always an octave higher than that by the latter.

Transverse Vibrations of Rods.

26. Verify the generalization that if the length of a rod fastened at one end is l and its thickness, in the plane of vibration, is d, all other

things being the same, the number n of vibrations per second (or in a given time) is such that

$$n \text{ varies as } \frac{1}{l^2} \text{ and } n \text{ varies as } d$$

or

$$n \text{ varies as } \frac{d}{l^2}$$

Clamp deal rod (S. A. 18) flatways (narrow face up) horizontally in the vice (S. A. 18) between two pieces of wood, so that 10 feet are free; set it vibrating horizontally. Adjust a pendulum bullet (S. A. 3) so as to oscillate with the rod. Adjust another bullet so as to oscillate twice as fast as the first. It will be found that the second pendulum will keep time with the rod (a) if the rod is 10 feet long and turned edgeways, (b) if it is made seven feet long and vibrates flatways ($10^2 = 2 \times 7^2$ nearly).

Combinations of Motions.

27. Fasten knitting needle (S. A. 19) in vice (S. A. 18), and fasten a bright bead on top of needle. View bead by light of one candle or one distant window. Strike or pluck in one direction. The bead will appear a straight line of light. While it is vibrating hit it in a direction at right angles to its motion and it will describe a circle or ellipse. Touch one side of it near the vice with a stiff feather and the ellipse will open and shut. Clamp the rectangular rod (S. A. 19) in the same way, and the figures obtained are parabolic, or 8-shaped. Touch one side with the feather and they vary.

28. A bright bead being fastened to one end of the spring (S. A. 20), the other is clamped at various distances in the vice, and various curves are traced out by the bead on the free end.

Analysis of Vibrations by Sinuosities.

29. Fasten the tuning forks (S. A. 6), which are a fork and its octave, in the vice (S. A. 18), clamping them between two pieces of wood. Fasten with beeswax on to the two prongs on one side two little styles of quill cut to fine flexible points. Soak a little cotton wool in turpentine, put it on a stone and set fire to it. Hold a glass plate (S. A. 21) over it till one side is covered with lamp-black. Set the two forks vibrating with the fiddle-bow (S. A. 21) and draw the smoked face of the glass across the styles, waved lines will be scratched on the glass; and the higher pitched fork produces twice as many waves in the same length as its lower octave fork.

Transverse Vibrations of Strings (Wires).

30. To show that the rate of vibration of a stretched string varies inversely as its length, other things being the same, fasten two similar iron wires to the wood-screws of the monochord (S. A. 22). Pass the other ends over the brass pullies and fasten equal weights to them, say 28 lbs., using the whole lengths of the wires from the fixed bridge to the pullies. Pluck the wires in the middle, and the same notes will be given. Insert one bridge half way between the one pulley and the bridge, the corresponding string gives the octave higher than the unshortened string. Insert bridge anywhere in the other string. Make one string half as long as the other, and the shorter string always gives the higher octave or twice as many vibrations in a second as the longer one.

31. To show that the number of vibrations varies with the square root of the stretching force or weight, fasten two weights over the pullies and let one weight be four times as great as the other. The wire with the heavier weight gives the octave higher than the one with the lighter weight. And this is the case if the bridges are inserted anywhere, provided the two are at the same distance from the pullies.

32. Combine results 30 and 31. That is, hang any two unequal weights from similar wire over the pullies, and use the whole length of the more weighted wire ; shift the bridge of the less weighted wire till the two give the same note. It is then found that if the wire A has the length l, and is stretched by the weight w, and the wire A_2 has the length l_2, and is stretched by the weight w_2, then when there is unison,

$$\frac{\sqrt{w_1}}{l_1}=\frac{\sqrt{w_2}}{l_2} \text{ or } \frac{w_1}{l_1^2}=\frac{w_2}{l_2^2}.$$

Verify this by altering the length of A.

33. From the above equation find out the weight of a lump of iron which is fastened to one wire by obtaining unison on shifting either its bridge or that of the other wire, which is stretched by a known weight.

34. Show that, other things being the same, the number of vibrations varies inversely with the thickness of the wire. Obtain the relative thicknesses of two iron wires by weighing equal lengths of them, and taking the square roots of their weights; vary the weights which stretch equal lengths till there is unison. Then find that the square roots of the stretching forces or weights are directly as the thicknesses. Or that therefore the stretching forces are as the squares of the thicknesses, *i.e.*, as the weights of the wires. Take equal stretching forces and vary the lengths till there is unison. Then find that the lengths are inversely as the thicknesses. That is, verify the following : where n is the number of vibrations per second, l the length, s the stretching force, d the thickness of the wire, and w the weight of a given length.

$$n_1 \text{ varies as } \frac{\sqrt{s_1}}{d_1}$$

$$\left(n_2 \text{ varies as } \frac{\sqrt{s_2}}{d_2}\right)$$

or if there is unison so that $n_1 = n_2$

$$\frac{n_1}{n_2}=1=\frac{\sqrt{s_1}\,d_2}{\sqrt{s_2}\,d_1}$$

$$\text{or } \frac{\sqrt{s_2}}{d_2}=\frac{\sqrt{s_1}}{d_1}$$

$$\text{or } \frac{s_2}{d_2^2}=\frac{s_1}{d_1^2}$$

$$\text{or } \frac{s_2}{w_2}=\frac{s_1}{w_1}$$

35. To obtain the relative diameters of wires of dissimilar metals, weigh equal lengths and take the square roots of the weights and divide these numbers by the respective specific gravities of the metals. The specific gravity is got by dividing the weight of any piece of the metal by the amount of weight it loses in water (that is by the weight of an equal volume of water).

36. The ordinary musical scale (unequal temperament) is as follows for any octave where n is the number of vibrations per second of the lowest note (tonic) :—

Note, Tonic.	Second.	Major, Third.	Fourth.	Fifth.	Major, Sixth.	Major, Seventh.	Octave.
n	$\frac{9}{8}n$	$\frac{5}{4}n$	$\frac{4}{3}n$	$\frac{3}{2}n$	$\frac{5}{3}n$	$\frac{15}{8}n$	$2n$

If the middle C is taken as having 256 vibrations a second, the eight complete notes from this C to its higher octave are—

C	D	E	F	G	A	B	C′
256	288	320	341·3	384	$426\cdot\dot{6}$	480	512

If the middle C is taken as 264 the numbers are—

C	D	E	F	G	A	B	C′
264	297	330	352	396	440	495	528

Divide the monochord (s. A. 22) scale, whose length from the fixed bridge to the peg or pullies is, say, l, into intervals of the lengths,

$$l, \quad \frac{8}{9}l, \quad \frac{4}{5}l, \quad \frac{3}{4}l, \quad \frac{2}{3}l, \quad \frac{3}{5}l, \quad \frac{8}{15}l, \quad \frac{1}{2}l,$$

Then whatever be the stretching force, these lengths, when the moveable bridge is placed at the corresponding marks, form a scale. The full length may be tuned by turning the peg or weighting over the pulley till it is in unison with a known fork, say A.

Nodes in Strings and Rods.

37. Slightly stretch, and rigidly fasten in a vertical position, the two ends of an empty caoutchouc tube (s. A. 1). Slightly pinch (damp) the middle and pluck the tube at a quarter from bottom ; on taking away the damping fingers a node remains there. Damp the tube at one-third and pluck at one-sixth from end, two nodes are formed and so on.

38. Use the stretched monochord wire instead of the tube. Place paper riders at every one-eighth of the wire's length. Touch the second one with a stiff feather and gently pluck the wire where the first is. The third, fifth, and seventh will be thrown off, while the second, fourth, and sixth remain.

39. Fasten a tuning fork (s. A. 6) upright in a vice (s. A. 18), tie a piece of cotton to the top of one prong, prevent its slipping by a little wax. Carry the thread over a smooth ring of wire and fasten a weighed cardboard tray to the other end. Let the two prongs of the fork and the thread be in one plane. Load the tray, and move the ring to and from the fork ; or, keeping the ring fixed vary the weight till, when the fork is bowed, there is only one segment, that is, the thread swings as a whole. Keeping now the length the same make the weight (reckoning the tray) only a quarter as great ; two segments are formed. If the weight be one-ninth as great there will be three segments ; if one-sixteenth there will be four.

If the string be at right angles to the fork's two prongs the segments formed are always twice as numerous as in the former cases, if the lengths and weights are the same as before.

40. Hold deal rod (s. A. 18) upright in hand, and by tilting the hand to and fro less or more rapidly, make one or more nodes. Mark the places of the nodes and measure the segments ; notice that the last division swings free, and is about half a segment in length.

41. Cut (s. A. 23) a strip of window glass about one inch wide, and any length l (about six inches) and lay it across two parallel strings at such a distance apart that each string is at quarter l from the end. Fasten

the strings to the glass with a little drop of wax in the middle of the glass. On hitting the glass in its centre a note will be produced resulting from the formation of one segment of length $\frac{l}{2}$ in the middle and two free half segments, each equal $\frac{l}{4}$. Since all these swing together the note may be considered as formed by an elastic rod of length $\frac{l}{4}$ fastened at one end (the node). Referring to 26 for the number of vibrations of a rod, and to 36 for the relative numbers of vibration in the gamut.

$$\frac{n_1}{n_2}=\frac{l_2^2}{l_1^2}$$

In this gamut $n_2=\frac{9}{8}n_1$, for the next whole note

$$\therefore \frac{8}{9}=\frac{l_2^2}{l_1^2} \text{ or } l_2=l_1\sqrt{\frac{8}{9}}$$

Similarly for the next whole note

$$l_3=l_1\sqrt{\frac{4}{5}}$$

And so on.

Calculate these lengths and cut strips of glass accordingly. Support and fix them with wax in a row on two horizontal threads making an angle with one another. Compare the motion of such bars with that of the water in a rectangular trough (s. A. 3) when the central line is elevated and depressed.

42. Hold fork (s. A. 6) horizontally and bow it; scatter sand on it. All is thrown off. Bow it near the root. A shriller note is produced, and some of the sand rests in a line—a nodal line—about $\frac{1}{3}$ of the fork's length from the end. Prove by monochord that the two notes are nearly as 1 : 9 (number of vibrations per second).

43. Remove clapper from hand bell (s. A. 14); fix it vertically upside down in vice (s. A. 18). Hold a pellet of sealing wax, the size of a pea, hung from a silk thread up against the edge of the bell. Bow the bell and move the pellet round, finding the four nodal points and the four regions of greatest motion. Nearly fill the bell with water and bow. Notice regions of comparative rest, and of disturbance. Move quickly in and out by the hands two opposite sides of an elastic wire (s. A. 22) hoop. Notice nodes and segments.

Beats.

44. Clamp two similar tuning forks (s. A. 6) in vice (s. A. 18) or screw them into board (s. A. 10) or monochord (s. A. 22). Load one near its root with a threepenny piece stuck on with wax. Bow both forks. Notice beats. Change threepenny for a sixpenny piece. The beats become more frequent. Move the coin higher up; the beats become still more frequent.

45. Determine rate of loaded fork with monochord (s. A. 22), knowing that of unloaded. Show that the number of beats per second is equal to the difference between the numbers of vibrations per second of the two forks.

46. Increase the load on one fork till harshness or dissonance ensues. Again compare rates.

Longitudinal Vibrations. Solids.

47. Clamp between edges of wood in the vice (s. A. 18) in the middle and horizontally the brass tube (s. A. 24). Rub one end longitudinally

with wash-leather (s. A. 24) covered with powdered rosin (s. A. 24). Hang a pellet of wax touching the other end. Observe how it is thrown off.

48. Let two glass tubes (s. A. 24), one twice as long as the other, be held, each in the middle, between finger and thumb, and let one end of each be rubbed with wet flannel longitudinally. The longer tube produces the lower octave of the shorter one. A wave of compression has to travel twice as far from the end to the centre and back in the former as in the latter case, and therefore takes twice as long, and accordingly in the same time re-appears and hits the air half as often. Prove this by stretching equally two pulley wires of the monochord and moving the bridges till the one wire is in unison with the one tube, and the other with the other tube. The wires are then found to be in length in the ratio of 2 : 1.

49. Take equal lengths of deal and oak rods (s. A. 24); hold them in the middle and rub ends with rosined leathers. The note from the oak is the deepest. Cut (s. A. 25) pieces off the oak rod till the notes are in unison. Measure the lengths. The lengths are in the proportion of the rates of progression of the compression wave in the respective rods. Because the compression has to travel from the end to the centre, and back again, in order to beat the air once to produce one sound wave.

50. To find the actual rate, tune by cutting, one of the rods to a tuning fork of known rate (No. of vibrations per second). This is best done by augmenting the sound of the fork by holding it over a resonant jar or cavity (see below 54). If the fork gives n vibrations to and fro in one second and the rod is in unison with it, the compression in the rod must travel from the end to the centre and back (that is, equal to the whole length of the rod) n times in 1 second. Assuming sound to travel in air 1,100 feet in 1 second, it travels in deal about 16,000 feet in a second.

51. Hold two similar wooden rods, one in the middle, and the other at a quarter its length from one end. Set both in longitudinal vibration, rubbing the shorter end of the second, octaves will be produced. The second rod will have a node at a quarter its length from the further end.

52. Wrap a piece of thin iron wire (s. A. 22) tightly into a close spiral round the brass rod (s. A. 24). Hang the spiral by one end, and hang a little weight at the other. Note with watch the number of jumps the wire gives in a few seconds when pulled out. Vary its length and the weight. Compare with half longitudinally vibrating rod clamped in the middle.

53. Fasten rigidly both ends of the wire spiral of 52, slightly stretched and vertical. Set the middle moving up and down. Also damp the middle and pull the centre of the lower half gently down and release it. The middle forms a node. Obtain two automatic nodes in a similar manner.

Open and closed (at one end) Tubes.

54. Fasten a piece of glass tubing (s. A. 26) about 18 inches long vertically. Fit a cork into the bottom. Through the cork pass a narrow piece of glass tubing. Fasten one end of a piece of vulcanized caoutchouc tubing about 3 feet long (s. A. 1) to this. To the other end of the elastic tubing attach the neck of a funnel (s. A. 15). Support the funnel on the filter stand (s. A. 26). Let the funnel be a little above the top of the tube. Fill both with water. Sound thd highest of the three forks (s. A. 6). Hold it over the upright tube, depress the funnel till the fork's note is greatly augmented. Lift the funnel up and down, and fix it when the augmentation of the fork's note (resonance) is greatest. Mark the height of the water in the tube exactly. Cut the

tube with a file (s. A. 25) about $\frac{1}{4}$ inch below mark. Grind it down on a wet hearth stone exactly to the mark. Cut and grind down several glass tubes of this same length. Make caps for the tubes by cutting round discs of cardboard as large as the outside of the tubes, these discs can be stuck on to the ends of the tubes with beeswax.

55. Show that if a fork resounds with a tube closed at one end of length l, it will resound with a tube open at both ends of length $2\,l$. To show the latter, fasten two tubes together by an inch of india-rubber tubing (s. A. 26).

56. Show that if a fork resounds with a tube of length l closed at one end it will resound with tubes closed at one end whose lengths are $3\,l$, $5\,l$, $7\,l$, etc.

57. Show that if a fork resounds with a tube open at both ends of length l_1 it will resound with tubes open at both ends whose lengths are $2\,l^1$, $3\,l^1$, $4\,l^1$, etc.

58. Show, as far as the forks at disposal will allow, that if a fork resounds with a tube closed at one end, those forks will resound with the same tube whose notes are the next octave but one, the next but three, and so on, above the first fork.

59. Show that if a fork resounds with an open tube all forks will do so whose notes are higher octaves of the first.

60. Admitting that for all notes—

$$\text{wave length in feet} = \frac{\text{number of feet traversed in } 1''}{\text{number of waves generated in } 1''}$$

and admitting that the resonant tube closed at one end is $\frac{1}{4}$ the wave length of the wave system of the lowest note which resounds in it, deduce (a) the rate of transmission of sound through air, knowing the number of vibrations of a fork and the length of the air column closed at one end or open at both, which resounds with it; (b) deduce the wave length, assuming the rate of propagation to be 1,100 feet a second, and knowing the pitch of the fork; (c) deduce the pitch of the fork, knowing the rate of propagation and the length of the resonant column.

61. Heat a closed tube, which resounds with a given fork, over an air-gas flame. Show that it no longer resounds. Invert the tube and fill it with coal gas. It no longer resounds. Use apparatus in 54. Get the tube when containing air to resound to a fork; fill it with carbonic acid (s. A. 16) by displacement; show that the column must be shortened to resound and compare lengths. This should verify the generalization that when d is the density,

$$\text{rate varies as } \sqrt{d}.$$

Effect of Relative Motion between Origin of Sound and Ear.

62. Fasten a whistle (s. A. 28) in one end of a caoutchouc tube about 6 feet long. Sound the whistle by blowing into the other end. Whirl the tube round while continuing to blow, and notice the alteration of pitch at different places. This is best heard at a distance.

Singing Flames.

63. Draw out a piece of glass tubing till the opening at the end is about as wide as a pin. Fasten to gas pipe, place vertically, and light. Reduce the flame to the height of about $\frac{1}{8}$ to $\frac{1}{4}$ inch. Clamp over it a glass tube so that the flame is about a quarter of the tube's length up the tube. The air in the tube will give a note. Place a similar jet and tube side by side with the former one. Provide each tube with a little sliding tube of paper so as to be able to alter the lengths, obtain perfect unison, and various beats. Show that the singing of the flame immediately begins if the voice is pitched to the note which the flames would give. Also start by a consonant tuning fork.

Artificial Larynx.

64. Grind off the top of a glass tube (s. A. 26) in two planes at an angle of about 60°. Stretch across the top two pieces of vulcanized caoutchouc (s. A. 29) in such a manner that there is a slight crack between them, bind the caoutchouc on to the tube with silk and blow through.

APPARATUS AND MATERIAL FOR ELEMENTARY EXPERIMENTS IN SOUND AND WAVES.

1. Three similar vulcanized caoutchouc tubes each about ¼ inch wide and 12 feet long. One filled with sand and tied up at the ends. A piece of similar tubing 6 feet long.

2. A long narrow wooden trough 4 feet × 6 inches × 6 inches caulked with marine glue, and painted inside. Preferably with one long face of glass. A block of wood 5¾ inches × 4 inches × 4 inches, with handle perpendicular from middle of one long face. Balls of wax mixed with iron filings so as just to float.

3. Two cylindrical zinc troughs about 2 feet and 18 inches diameter, and 18 inches deep. A rectangular trough 2 feet × 1 foot × 18 inches. Silk thread, leaden bullets. A beaker with bottom about 3 inches diameter.

4. A box about 18 inches cube, one side removed and replaced by sail cloth nailed tight on. The seams of the box made tight by paper pasted on the inside. A circular hole in the opposite side of the box to the canvas. The hole can be covered by a plane piece of cardboard. Two holes, side by side on one side of the box, into which pass glass tubes bent at right angles, the other ends of which pass through corks in the necks of two flasks, one containing ammonia and the other hydro-chloric acid.

5. Two air-gas burners with tubes.

5*a*. Fasten a tin or glass tube, ⅛ inch diameter, to the middle of a circular plate of tin-plate or cardboard about 6 inches in diameter, with a hole in the middle on which the tube fits. A circular piece of cardboard somewhat less than the disc.

6. A toy air ball, the larger the better. Three tuning forks, two alike and one an octave higher.

7. A glass tube about ¼ inch internal diameter and 50 inches long, smoothly and as flatly as possible closed at one end. The tube is bent into two parallel limbs at a distance of about 10 inches from the closed end. It is fastened to an upright board upon which are ruled horizontal lines $\frac{1}{10}$th inch apart. Enough mercury to fill the tube.

8. A stout glass tube about ½ inch internal diameter and 6 inch long, closed at one end by a cork which is made air-tight by sealing wax. A cylindrical wooden rod just passing into the tube, wrapped round at one end with silk thread till it just fits the tube. The silk is oiled or covered with glycerine. A piece of German tinder. A little bisulphide of carbon.

9. A dozen marbles or "solitaire" balls.

10. A deal rod, any shape, 12 feet long, covered with list, hung from threads or clamped horizontally. A square thin deal board, not cracked, about 2 feet square.

11. A glass tube about 18 inch long and ½ inch wide, closed at one end, is fastened perpendicularly by a little wax to the board (in 10) which is supported on three corks. The tuning fork (6) has a little cone of cork fastened to one face of one prong, by beeswax.

12. Two tinned iron tubes, each about 3 feet long and 4 inches diameter; the end of one fits into the end of the other.

13. A pointed deal rod, about 6 inches long, fastened to a square light deal board 5 inches square.

14. A hand bell, the larger the better.

15. A glass funnel about 4 inches in diameter. A cork to fit its neck. A clamp or support for the funnel. Carbonate of soda, tartaric acid.

16. A 1 lb. flask, fitted with a cork through which pass air-tight (a) a straight tube reaching to the bottom with a funnel at the top, (b) a tube bent at right angles, which just passes through the cork. Pieces of marble. Hydrochloric acid.

17. A large humming top with a smooth button driven into its peg. Filled with sand and closed. Resting upon the body of the top and fastened to it is a horizontal disc of thin iron plate, having 200 or 300 teeth in its circumference. Also two rings of holes near the circumference. One ring having twice as many holes as the other. A piece of quill glass tubing bent to 135° at one end.

18. A deal rod, about 12 feet long, 1 inch wide, and $\frac{1}{2}$ inch thick. The ratio of width to thickness should be very exact. A table vice.

19. A round knitting needle. Some hollow silvered glass beads. A square steel rod, about 8 inches long, and $\frac{1}{10}$ inch square. A rectangular steel rod, about 8 inches long; one side $\frac{1}{10}$ inch, the other $\frac{1}{20}$ inch. The ratio should be very exact.

20. A straight piece of clock spring, about 1 foot long, is softened in the middle in the flame of an air-gas burner, and twisted so that the planes of the two parts are at right angles to one another.

21. A fiddle bow. Some sheets of glass, 3 inches × 4 inches. Some oil of turpentine.

22. *Monochord, etc.* An inch deal board, 3 feet long, 9 inches wide. Two pieces of wood, 6 inches × 1 inch × 1 inch, screwed on across ends to form supports. Three long wood screws driven in obliquely (slanting outwards) at one end at equal distances. At the other end, opposite one screw, is a pianoforte peg, at an angle of 45. Opposite the other two screws are two brass pullies (window blind pullies) on stems which are driven in at an angle of 45°. A bridge, that is, a triangular wedge of hard wood, 9 inches long, $\frac{1}{4}$ inch wide at base, and as high as the pullies. This is screwed from below across the board about 3 inches from the wooden screws. Three other little moveable bridges about 1 inch long, as high as the pullies, are provided. A variety of weights and hooks. A pair of pliers. Several yards of iron wire (pianoforte wire) of different thicknesses. Brass wire, some of which has the same thickness as some of the iron wire. The ends of three pieces of wire are twisted into loops and passed over the screw heads. One of the other ends is passed through the pianoforte peg which is then twisted round by the pliers. The other two have loops twisted in them, and passing over the pullies carry weights. A sheet of paper is gummed to the board having lines at every inch, and thinner ones at every $\frac{1}{10}$th inch. Mark with 0 the line beneath the pullies and at the pianoforte peg.

23. A sheet of window glass. 2 square feet of patent plate glass. A glazier's diamond or steel wheel glass cutter.

24. Severel round deal and oak rods, 6 feet long, $\frac{1}{2}$ inch diameter. One brass rod or tube $\frac{1}{2}$ inch diameter, 3 feet long. Glass tube, $\frac{1}{4}$ inch diameter, 3 feet long. A square foot of flannel. A piece of wash-leather. Some powdered rosin.

25. Small hand saw. Small triangular file.

26. Twelve feet stout glass tubing, $\frac{3}{4}$ inch internal diameter. A few inches of $\frac{1}{8}$ inch tubing. A filter stand and a retort stand. A few feet of vulcanized caoutchouc tubing, $\frac{1}{2}$ inch internal diameter.

27. A dog whistle without the pea.

28. A few square inches of thin vulcanized sheet caoutchouc.

SUBJECT VIII.—ELEMENTARY EXPERIMENTS IN LIGHT.

N.B.—*The numbers between brackets refer to the numbers in the list of apparatus and material.*. S. A. *signifies sound apparatus, p.* 10; L. A. *light apparatus, p.* 19.

Sources of Light.

1. Show that most sources of artificial light are processes of combustion giving rise to water and carbonic acid. Hold for a few seconds dry bottles (L. A. 1) over flame of candle, gas, lamp, &c. Notice deposition of water. Turn the bottle over, add a tablespoonful of lime water (L. A. 1), put in stopper, shake up, and notice formation of carbonate of calcium.

Comparative Luminosity of Hot Bodies.

2. Hold air-gas burner (S. A. 6) sideways and drip powdered quicklime through the flame; also powdered salt.

3. Hold a piece of white earthenware in the air-gas flame. Notice no deposition of soot. Hold the same in a candle or in the flame of an ordinary fish-tail burner. Notice the deposition of soot.

4. Heat red-hot in a clear fire in a dark room a piece of earthenware, having a dark pattern, such as the "willow" pattern. Notice that as long as the room is dark, so that the plate is seen by emitted light, you see a bright pattern on a dull background. Turn up the gas or light a candle. Seen by reflected light the pattern is dark on a bright background.

Phosphorescence, Fluorescence, and Insolation.

5. Rub together two pieces of loaf sugar in the dark. Also two quartz pebbles ("milk stones").

6. Heat over air-gas burner (S. A. 6) a sheet of iron (L. A. 2) on a retort stand (S. A. 26), and scatter on it powdered fluor spar and also bone ashes. Notice the emitted light.

7. Expose powder in glass tube of (L. A. 3), to bright light, then view it in the dark.

Intensity.

8. Fill smaller of tin trays (L. A. 4) with water, and pour into larger tray, showing that the depth is inversely as the area. Compare depth with intensity.

9. Stencil (dab over with putty) two of the flasks (L. A. 5). Join the terminals of the battery to spiral of platinum wire, so arranged as to pass into the necks of the flasks. Place the two flasks in succession over the wire, and show that the intensity of the light on the flasks or quantity of light on the unit of area is inversely as the surface, that is, inversely as the square of the flasks' radii, that is inversely as the squares of the distances of the glass surfaces from the source of light.

10. Make a tall rectangular pyramid of wire (S. A. 22). Stretch across the base three threads at equal distances parallel to one side, and three parallel to the adjacent side, so as to divide the base into 16 squares. Fasten a square of wire around the pyramid half-way up, and tie two threads across it, bisecting the sides, thus forming four squares. At a quarter distance from the top fasten a square around. All the squares are equal.

11. Fasten a square of wire in a clamp, and place it in an otherwise dark room, half way between a candle and the wall. Cut a square sheet of paper so as just to cover the shadow of the frame. Fold it across and across, and it will fit the frame itself.

Light Moves in Straight Lines.

12. Place a stick vertically between the wall and a long thin luminous gas flame. Use tube for singing flame. *See* Sound, 63. Notice that the shadow of the stick is sharply defined. Place stick or flame horizontally. Show penumbra.

13. Make a pinhole camera. Make two pasteboard tubes by rolling pasted paper on a wooden cylinder, so that one fits inside the other. For the wider tube, previously cover the cylinder with dry paper. Cover one end of the wide tube with tinfoil, and make a pin-hole in the middle. Cover one end of the narrower tube with tissue paper, and thrust this end in the wider tube. Line with black paper. Notice pictures on the tissue paper.

Photometry.

14. *Shadow Photometer.*—Place an opaque rod of not less than 1 in. diameter vertically at about three feet from a white screen. Place a candle about two feet further off nearly in the plane through the rod perpendicular to the screen. Place another candle so near the first that the two shadows are close together. Move one candle to-and-fro till the shadows are of equal depth, that is, are equally illuminated. The brighter light will be furthest off. The illuminating powers are in the proportion of the squares of the respective distances from the screen. Confirm this by making a cluster of two or three candles close together at one place, and using a single candle of the same brightness at the other.

Transparency Photometer.

15. Soak a round spot of beeswax into a piece of white writing paper. Cut a circle out, leaving the wax in the middle. Fasten the paper over a wire ring about 4 in. in diameter, having a stem about 12 in. long. Fasten the stem into a block of wood about 3 in. $\times$ 1 in. $\times$ 2 in. Mark on the side of the block a line just under the paper. Mark on the table or on a board 6 ft. $\times$ 4 in. $\times$ $\frac{1}{4}$ in. a scale of inches and tenths of inches. Place at one end of the scale two equally bright candles in an otherwise dark room, and at the other one also equally bright. Move the paper until looking from one side the wax spot disappears. Look from the other side, and if necessary move the paper again. Take the mean of the readings. The square of the distance from the single candle should be half the square of the distance from the two. Vary the number of candles at both ends and confirm. Compare the illuminating power of a fish-tail gas burner with that of a candle.

Law of Reflexion.

16. Fasten a little whitened wooden stick with wax perpendicularly at the centre of a plane looking-glass. Cast upon the mirror at the foot of the rod a beam of parallel rays from the lantern (L. A. 7) or a sunbeam coming through a hole in a screen. Notice (*a*) that the reflected beam always makes the same angles with the mirror and the stick as the incident beam does, and (*b*) that the incident beam, the stick, and the reflected beam all lie in one plane.

17. Out of a wooden board (L. A. 9) cut a sector having an angle of 60°. Leave a little wood in the apex to include the centre. Fasten an arm as long as the radius to a point tapering to one end upon the sector by means of a wood screw in such a manner that its thick end is pivoted to the centre of the sector and its pointed end moves on the circumference. At about half way down one side of the sector fasten in a vertical plane parallel to the other side a piece of silvered glass (L. A. 8) about 1 square inch, having its upper half cleared of the silver. Fasten a piece of silvered glass about 2 in. square in a

vertical plane on the moveable arm parallel to it and above the pivot facing the other mirror. Fasten a narrow straight tube of paper on the second side of the sector as far from the centre as the mirror on the other side; let the tube be parallel to the chord of the sector's arc and be horizontal. It is directed to the half silvered mirror. Bring the arm so that the two mirrors are parallel. Mark with 0° the point where the point of the arm crosses the arc. Divide the arc into degrees. This forms a model of a sextant. One object is seen directly through the tube and through the plain upper part of the mirror facing the tube. By moving the arm, another object is seen after reflexion, first from the moveable and then from the fixed mirror. The arm being moved till these two images coincide, the angle extended between the object is equal to twice the angle read off on the scale.

18. At one end of a piece of board 1 ft. long by 4 in. wide fasten by sealing wax a cork upright, through this pass horizontally a piece of glass tube about 2 in. long and $\frac{1}{4}$ in. internal diameter. Stretch a vertical thread across the opening of the tube nearest the other end of the board. Towards the other end on the same side fasten a circular sheet of cardboard divided into degrees, the 0° being nearest to the tube and in the middle of the board. Pivot in the centre of the circle two radial arms one above the other, one carrying at its end a vertical pin, the other a central mark. The second carries a 2 in. square piece of silvered glass (L. A. 8) in a vertical plane perpendicular to the arm. The pin-bearing arm being placed anywhere, the mirror-bearing arm is turned till the reflexion of the pin is seen and coincides with the thread in the tube. Whenever this is the case, the reading of degrees where the pin is always twice as great as where the marked arm is.

19. Fasten a piece of wood 10 in. $\times$ 1 in. $\times$ $\frac{1}{2}$ in. with its 1 in. face along the middle of a board 4 in. $\times$ 1 ft. At one end of the piece fasten an upright 1 in. wide, 6 in. high, bevelled off at the top to a horizontal edge. Bend two pieces of tinned iron plate 2 in. long 1 in. wide into saddles so as to slide tightly along the central piece of wood. Upon one of these fasten a square inch of silvered glass (L. A. 8); upon the other a piece of glass of the same size blackened at the back. Make a transverse ink mark across both glasses in the middle. Carry down pointers from the saddles opposite these lines to a scale of lengths on the board beginning with 0 at the foot of the upright vertically below the edge. Get the instrument perfectly level. Look over the edge and move the sliding mirror till the reflexion of an object high above the ground, such as the top edge of the wall of a room, coincides with the line on the glass. Measure distance from base of upright to index (a), from index to wall (b), length of upright (c), then if (h) be the height of the ceiling—

$$h = c\,\frac{b}{a}.$$

Multiple Reflexions.

20. Cut two pieces of silvered glass (L. A. 8) 4 in. $\times$ 3 in. Paste a calico on the back of both so as to form a hinge. Place lighted candle between the two and examine the number of reflexions. Place mirrors upright with hinge above centre of small graduated circle and show that the number of images seen is $\frac{360^\circ}{a^\circ} - 1$ if a be the angle between the mirrors.

21. View a candle flame in a piece of silvered glass held horizontally and notice that if the angle of incidence (the angle between the light ray and the perpendicular to the surface) is considerable, two images are

seen. The highest, that formed by the glass, becomes brighter as the angle of incidence increases. Throw a parallel beam from the lantern through a narrow hole (L. A. 7) and focus the hole on a screen by a lens (L. A. 7). Catch the beam obliquely on a piece of silvered glass and notice the two images.

Cast the beam on a slab of plate glass at various obliquities, and notice the two families of spots of light, (1) those which are reflected and after more or less frequent reverberation escape on the same side as the lantern, and those which pass through after more or less reverberation and appear on the other side.

22. Blacken a sheet of plate glass on one side by holding it in the flame of ignited oil of turpentine. Show that only one image of a flame is seen and only one spot of light is formed.

Superposition of Images.

23. Cover a lantern cap with tinfoil, remove the condensing lens, and place the cap on. Make pin-holes in the cap. For every pin-hole there is an image formed on the screen. Make the pin-holes more and more numerous, and near together, till the images overlap and become confused. At last diffused light is produced, which is an overlapping of images.

Dispersion.

24. Put a candle at one end of a tube (S. L. 12), and screen off all light except that which passes down the tube, reflect this on to a screen by a plane mirror (L. A. 8). Breathe upon the middle of the mirror through a glass tube. Notice the dark spot produced on the screen.

Reflexion from Curved Surfaces.

25. *Principal Focus.*—Use one of the concave spherical mirrors of (L. A. 13, 14, 15). Show in an otherwise dark room that if a candle is at twenty feet distance the light will be focussed to a point half way between the centre of the mirror and its centre of curvature. Catch the light so focussed on a small paper screen (L. A. 16).

26. *Spherical aberration.*—Show that the light is more localised but less bright if the central part only of the mirror is used. Catch sunlight obliquely on the rim of a cup of inky water. Observe "caustic" curve, the cusp being half way between the edge and the centre.

27. Advance distant candle flame of 25 towards the mirror, move it up or down. Show that the focus advances to meet the light and that when the light is raised the focus is depressed, and the converse. Show that when the candle flame is at the centre of curvature there also is the focus. When the flame is between the centre of curvature and the principal focus the focus of the flame is further away than the principal focus. When the flame is in the principal focus the reflected rays are parallel, or the focus is at an infinite distance. When the flame is still nearer the reflected rays diverge, so that they cannot be caught on a screen, but appear to come from a point behind the mirror. Repeat all these with a fish-tail burner and notice the inversion of the image in all cases but the last. Notice that in all cases where a real image is formed the flame and the image may change places.

When a real image is between yourself and the mirror show that the image can be magnified by a lens. (Astronomical reflecting telescope.)

28. Cast parallel beam on convex surface, notice its dispersion. Hence deduce virtual, upright, diminished image.

Transmission and Refraction.

29. Place a coin at the bottom of a basin and place the basin so that the coin is hidden by the edge. Pour in water till the coin becomes visible.

30. Stretch a wire across opening in cap of lantern (L. A. 7). Focus shadow of wire on screen. Interpose strip of glass (L. A. 17) in front of wire and tilt the strip. Notice displacement of part of shadow.

31. Fill cell (L. A. 18) partly with water, cast half shadow of wire through it as in 29. Place cell obliquely. Partly fill all with bisulphide of carbon, then add water. Let the shadow pass partly through the bisulphide, partly through the water, and partly above the water; twist the cell.

32. Focus on the screen a small circular hole in the cap of the lantern. Introduce wedge of glass and show that the spot is moved towards the base of the wedge. Let the first face of the wedge be oblique to the beam. Put the second wedge with the first, face to face and base to base, so as to form a single wedge of double the angle. Notice the double displacement of the light spot. Put then edge to base; notice the emergent beam is parallel to the incident.

33. Place the cell (L. A. 18) before the lantern and focus it on the screen. Let the surface of the water be visible. Add a lump of ice on the water, observe the streakiness of the light. Add syrup, alcohol, and hot water, by a pipette. Pour the vapour of ether (L. A. 19) out of a bottle. Examine shadow of burning gas, red hot poker and platinum wire, through which a current of electricity is passing (L. A. 6).

Law of Refraction.

34. Employ the apparatus (L. A. 20). Cover up window all but a vertical slit in the middle. Half fill the trough with water. Let a beam from the lantern (L. A. 7) fall obliquely on the slit; part passes above and part through the water. Place the straight edge on the top of the trough through the centre and perpendicular to the diameter. Measure by the T-square the perpendicular distance from the points where the two rays meet the semicircle to the straight edge. The ratio of these lines is constant wherever the lantern is placed.

35. Add dry ether to dry bisulphide of carbon, about four of the latter to one of the former, till a part of the glass rod immersed dissappears.

Total Refraction.

36. Place a coin in a round wine glass (white), fill the glass quarter full with water; hold it above the head and look up at the water surface. Notice the reflection of the coin. Plunge an empty test tube (L. A. 19) into the water and notice the metallic appearance of the immersed parts. Fill the tube with water and observe the disappearance of the lustre. Notice the metallic appearance of a cabbage leaf when beneath the surface of water.

37. Turn the side of the rectangular prism (L. A. 21) facing a candle. Look through the other side and notice the reflection of the candle on the hypothenuse face. Look at an object interposing the right-angled prism in such a way that its hypothenuse is parallel to the direction of the light from the object. Observe inversion.

38. Empoly right-angled prism as *camera lucida*. Hold the prism with its right angle edge horizontal. One face containing the right angle away from the body and vertical, the other horizontal. Place the eye just over the edge next the body. Notice inverted reflection of distant objects, also paper beneath. Draw outline of object on paper.

Lenses.

39. Determine principal focus of a double convex or plano-convex lens. This is done by measuring distance from lens where the focus of a distant point or image of a distant body, say sun or moon, is formed with a lens.

40. Make a series of experiments similar to those of 27, that is, examine image of fish-tail burner when the burner is 20 feet off. Catch the image (close to the principal focus) on a screen (L. A. 16) on the other side of the lens. Notice the image is smaller than the flame and inverted. Advance the burner towards the lens. Observe the image grow in size, and retreat from the lens. When the flame and its image are of equal size they are equidistant from the lens (this corresponds with the flame and image, both being in the centre of curvature of the concave mirror). Advance the flame nearer; the image increases and retreats. When the flame reaches the principal focus the refracted rays are parallel, or the focus is at an infinite distance. Nearer yet, the rays after refraction diverge, and would meet if produced on the same side of the lens as the flame. Hence deduce magnifying property of common lens when held near the eye or near an object. Show that the image and object may always change places if there is a real image. Being on the same side of the lens as a real image, magnify the image by a hand lens. (Astronomical refracting telescope.)

41. Verify the formula—

$$\frac{1}{f} = \frac{1}{a} + \frac{1}{b} \text{ or } f = \frac{ab}{a+b}.$$

If f is the principal focal distance, a the distance of an object, and b that of its image, all measured from the centre of the lens.

Spherical Aberration of Lenses.

42. Cut a cardboard disc as large as a lens, cut a ring of holes near the circumference and also a ring near the centre. Fasten the disc on to a plano-convex or double convex lens. Examine by sunlight or parallel rays from the lantern. Catch refracted beams on screen. Move screen away from lens. The outer ring of spots are the first to cross one another and form an image. Further away the inner ring of beams coincide, forming an image. The outer ones having crossed form a ring of spots.

Model of Eye.

43. Fill 8 oz. flask (L. A. 5) with distilled water (eye ball). Cover one side half with black paper having a round hole in it (iris and pupil). Place slightly convex lens in front of hole (cornea and crystalline lens combined; the latter outside the eyeball instead of inside). Place a lighted candle in front of the hole (object); catch (inverted) image of candle on paper screen behind globe (retina). Move the candles a little away from globe. The image becomes indistinct. Restore it by interposing another convex lens (cure of long sight). Bring the candle near to the globe till the image is indistinct. Interpose concave lens to restore the clearness (cure of short sight).

Properties of Eye.

44. *Blind Spot.*—Make two dots on paper two inches apart. Close the left eye and bring the right one over the left spot. At a distance of about 6 inches the right spot becomes invisible.

45. *Duration of Images.*—Whirl round smouldering end of string. Cut cardboard circular disc, and fasten it on humming top (S. A. 17). Blacken two quadrants. Notice grey hue when the top spins.

Fasten brass wires of various shapes projecting from bottom of upper axis of top. Notice appearance of cups and vases.

46. *Irradiation.*—Pass electric current from 4 Grove's cells through thin platinum wire (L. A. 6). Notice the wire appears thick and laminated. View it through various coloured glass. Observe how its thickness appears to diminish.

Analysis and Synthesis of White Light. In these Experiments the Sun Light is used where available instead of the Lantern.

47. Put cap with wide vertical slit on the lantern; focus slit on screen by lens. Interpose beyond lens an equilateral prism with its refracting angle vertical. Let the slice of light fall upon the first face of the prism at such an angle that the average light in the prism is parallel to the base. Notice the image is fringed with red light on one edge and violet on the other. Employ a slit about $\frac{1}{10}$ inch wide. Notice the whole of the image is coloured: violet towards base of prism, then blue, green, yellow, orange, and red. (Formation of spectrum.) Turn prism on a vertical axis till the deviation (total refraction of the spectrum) is least. Catch spectrum on second equilateral prism, so placed that the bases are towards the same parts, and that the second causes the minimum deviation of the light from the first. Notice increased length of spectrum. Turn the second prism round, so that its base is towards the edge of the first, and the two contiguous faces (and therefore the other two vertical faces) are parallel. Notice the synthesis effected by the second prism of the spectrum produced by the first. Interpose an opaque plate with vertical edge between the prism, first towards the base and then towards the edge of the first prism. Notice the residue of colour in the spectrum. Introduce between the prism slowly with its refracting edge vertical a glass wedge (L. A. 17). Notice the removal of a coloured hand towards the base of the interposed wedge, and the residual colouration of the spectrum.

48. Paint disc of cardboard in segments of violet, blue, green, yellow, orange, and red; fasten it on top (S. A. 17) and spin. Notice the blending of the colours by retention of images into a grey.

49. Focus horizontal slit on screen and interpose trough (S. A. 24). Leaving one cell empty. Fill one with water, the next with alcohol, the next with turpentine, the next with benzol, and the last with bisulphide of carbon. Push the trough along so that the slit of light may fall on each in succession. Notice (*a*) the increased refraction of the spectrum as a whole, and (*b*) the increased elongation of the spectrum.

Colour.

50. Make a solution of sulphate of copper, 2 of sulphate to 20 of water (L. A. 22). Add ammonia till the precipitate is re-dissolved. Place solution in glass cell (L. A. 18). Focus a round hole in lantern cut on screen. Interpose above solution. Notice pure blue colour. Interpose red glass either before or after the cell. Notice total extinction of light.

51. Employ slit on lantern $\frac{1}{8}$ inch wide. Focus on screen. Interpose glass cell (L. A. 18), containing a solution of permanganate of potassium (L. A. 22). Observe rich purple colour. Make the solution as strong as possible so that the colour is distinct. Analyse the light by a prism, note pure red and blue bands. Take a narrower slit. Analyse the light first by a prism and then, beyond the prism, interpose the permanganate solution. Dilute the solution and notice the bands. Try in the same way various transparent coloured liquids which you may have, both organic and inorganic, including diluted blood.

52. Paint sheets of cardboard with various brilliant colours. Send the light in an otherwise dark room upon these, and catch reflected light on white sheets of cardboard.

53. Use the bisulphide prism (L. A. 25) to produce a long spectrum of a slit on lantern cap. Pass through the spectrum (*a*) the glass cell containing as many coloured transparent solutions as you have. Notice the shadow of the cell. Pass through the same spectrum various coloured opaque bodies, such as flowers.

54. Sprinkle salt on the wick of the spirit lamp (L. A. 26); view flowers and other coloured opaque bodies by this light.

55. Put a few copper turnings in a test tube, add a little nitric acid. Hold the tube causing the coloured vapour before the slit; analyse by the bisulphide prism: notice the black bands.

SUBJECT VIII.—APPARATUS AND MATERIAL FOR ELEMENTARY EXPERIMENTS IN LIGHT.

1. One pound of quick lime. Two four-ounce stoppered bottles. Slake a piece of lime the size of a walnut, shake it up with water in one of the bottles and let it stand till clear, forming lime-water.

2. A few ounces of fluor spar (Derbyshire spar), an ounce of phosphate of calcium (bone ashes). A sheet of iron plate, about 1 square foot.

3. Three sticks of sulphur. Powdered burnt oyster shells. A Hessian crucible with cover. Mix powdered oyster shells with half the weight of sulphur (1 oz. $\frac{1}{2}$ oz.) Heat in the crucible in the fire white hot. Take out, let cool, powder and seal in glass tube. The powder is an oxysulphide of calcium.

4. Two tin trays, water-tight, one 1 square foot, the other square 6 inches. Each 4 inches deep.

5. Twelve round-bottomed wide-necked flasks, 1 lb., 8 oz., 4 oz., and 2 oz. Three of 4 oz. Six of 2 oz.

6. A battery of 4 platino-zinc cells, with nitric and dilute sulphuric acid. For the setting up of this battery see apparatus for Experiments in Electricity. A piece of thin platinum wire about 1 foot long.

7. A magic lantern with a condensing lens capable of throwing a nearly parallel beam. Several caps with round holes in them of various sizes. Also slits from $\frac{1}{4}$ inch to $\frac{1}{100}$ inch. A hand reading glass or double convex lens. About 2 feet principal focus (see 38). Several other lenses: one plano-convex, another plano-concave.

8. A plane looking-glass; better without the frame. A square foot of silvered glass varnished at the back (for cutting up).

9. A deal plank planed on both sides $\frac{3}{4}$ inch (for cutting up).

10. Three square feet of tinned iron plate, one for cutting up.

11. Twelve square feet of tin foil.

12. Half an ounce of nitrate of silver.

13. Cut out with a point of glowing charcoal circular pieces from a spherical glass globe (bolt head). Smooth the edges on a wet grindstone or hearthstone.

14. *To silver Glass.*—Dissolve 154 grains of nitrate of silver in 17 fluid ounces cf distilled water. Add ammonia until the precipitate formed is nearly redissolved. Filter and add distilled water so as to make the whole 34 fluid ounces. This gives solution A. 31 grains of nitrate of silver are dissolved in 34 fluid ounces of boiling distilled water, dissolve 23 grains of Rochelle salt in a small quantity of water, add it to the boiling nitrate, boil till the precipitate formed becomes grey. Filter and allow to cool. This

gives solution B. To silver a glass object it must be perfectly clean. It should be rubbed with strong nitric acid. A stick is dipped in the acid and rubbed on. The acid is washed off and caustic potash is used; this is washed off and alcohol is used. Finally, this is washed off with distilled water, and the object is placed with the side uppermost which has to be silvered in a clean dish. While still wet, equal quantities of the solutions A and B are poured over the object and mixed. In about 2 hours, according to the temperature, the silvering is complete; the hotter the quicker; the slower the better. The object is taken out washed, the superfluous silver cleaned off, dried; the silvered side may be varnished. Or, if the coating be thick, the silver surface itself may be exposed and polished with rouge powder on cotton wool.

15. The pieces of glass in L. A. 13 are silvered by the process in L. A. 14. Some on the convex and some on the concave faces. They are supported in wire claws grasping the edges.

16. Stretch pieces of paper over wire hoops having wire handles. The hoops to be from 1 inch diameter to 8 inches.

17. A strip of plate glass $\frac{1}{4}$ inch thick. Two wedges of glass about 1 square inch face and $\frac{1}{8}$ inch thick at base.

18. *A Glass Cell.*—Cut a slab of plate glass 3 inches × $1\frac{1}{2}$ inches to form a base; (*a*) cut 2 squares $2\frac{1}{2}$ inches of thin flat glass to form faces; (*b*) cut 2 pieces of plate glass $2\frac{1}{2}$ inches × $\frac{1}{2}$ inch to form sides; (*c*) cut one piece $2\frac{1}{2}$ inches × $\frac{1}{2}$ inch to form bottom (*d*); with marine glue cement *d* upon *a* in the middle. Cement *c* upright at ends of *d*; cement faces *a*.

19. Two ounces of sulphuric ether. Two ounces of alcohol. A few test tubes. Two glass rods.

20. A semicircular tin tray 2 feet diameter, 4 inch deep; a glass window $\frac{1}{2}$ inch wide in centre of diameter. Painted black. Graduated in equal arcs on inside of semicircle, the 0° being opposite to the window. A straight edge and a small T square with scale.

21. Two equiangular glass prisms. A rectangular glass prism. The larger the better; not less than 1 inch face with the equilateral and $1\frac{1}{2}$ inches hypothenuse face with the rectangular.

22. Square 9 inches of variously stained glass, several depths of pure blue, deep red, yellow, and green. Sulphate of copper. Permanganate of potassium.

23. Two ounces isinglass, 3 ounces glacial acetic acid, mix equal weights to make a cement; warm when necessary.

24. *Divided Trough.*—Cut two strips of flat glass 9 inches by 2 inches. Grind two long edges off at 30°. Cut seven equilateral triangles of glass 1 inch side. Cement the strips together making angle of 60° and insert triangles in ends, and also intermediately to make compound trough with the cement of 23. Bind together and renew cement with quill feather.

25. *Make a Bisulphide of Carbon Prism.*—Grind off the ends of a stout glass tube 2 inches long (S. A. 26) obliquely at 60°, so that the edge of their intersecting planes is at right angles to the axis of the tubes. Make a drill. Soften the end of a triangular file by heating it and letting it cool slowly. Grind, on a stone with water, and hone with oil, the point into an acute rectangular pyramid. Harden by heating red-hot and quenching in water. Bore with this, using a little turpentine in hole in the side of the above tube. With some of the cement of (L. A. 23) cement two very smooth sheets of glass (Microscope plates) to the two oblique ends. Fill the tube through the hole with bisulphide of carbon; cork up and glue over.

26. A spirit lamp. Copper turnings.

SUBJECT VIII.—ELEMENTARY EXPERIMENTS IN HEAT.

N.B.—*The numbers between brackets refer to the numbers in the lists of apparatus and material.* S. A. *signifies sound apparatus, p.* 10 ; S. L. *signifies light apparatus, p.* 19 ; S. H. *signifies heat apparatus, p.* 30.

Sensation.

1. Plunge one hand into hot water, the other into ice-cold water. Plunge both into lukewarm water. Notice that the cooled hand feels warm and the warmed hand cool.

HEAT OF CONDUCTION.

Expansion.

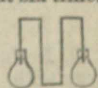
2. Cut a round hole in a sheet of tin plate (L. A. 10), exactly large enough to let a round bottomed 4 oz. flask (L. A. 5) pass through. Fill the flask with boiling water; it will not pass through till the plate has got warm. Stretch a long piece of platinum wire between metallic supports. Heat it by means of a galvanic current (L. A. 6). It becomes slack.

3. Fit with corks the necks of the three 4 oz. flasks (L. A. 5). Fit tightly into the corks three narrow glass tubes open at both ends. Fill the flasks with water, alcohol, and oil of turpentine respectively. Push in the corks till the liquid stands in each at the same height. Put all three to the same depth into a vessel of warm water. Notice that the expansion of the glass causes a momentary sinking of the liquids; that ultimately the expansions are very different.

4. Fit a 2 oz. flask with a tight cork through which a tube passes, the other end of which is bent down and then up at the end. Clamp the flask so that the end of the tube dips under water in a basin. Fill a test tube with water and invert it over the end of the tube. Warm the air in the flask and collect the expelled air in the test tube.

5. Fit tightly a cork through which a straight tube passes into the neck of a 2 oz. flask. Turn over and pass the tube through the cork in the neck of a wide-mouthed bottle containing coloured water. Warm the flask with the hand so as to expel some of the air and let the liquid rise in the stem. (An air thermometer.)

6. Fasten two such flasks together air-tight by a tube bent six times at right angles and containing some coloured liquid in the middle bend. Show that the liquid moves if one flask is warmed more than the other.



7. Solder together side by side a brass and iron wire (H. A. 1), each about 2 feet long. Hammer the compound wire straight and notice how it bends when heated. Fuse a piece of platinum wire through the side of a glass tube, and notice that the glass does not crack on cooling.

8. Fit corks and bent tubes into two flasks as in 5. Fill one tube with air and the other with coal gas. Cover equally in the same vessel with hot water. Collect expelled gas in two test tubes full of water. Show that the quantities driven out are nearly equal.

Force of Expansion.

9. Place a hermetically sealed tube (L. A. 2) in a basin, cover it with a cloth and pour hot water on it. Notice it burst.

Thermometer.

10. Place thermometer amongst pieces of melting ice. Also in boiling water. Note the temperature 0° C. and 100° C. (32° F. and 212° F.) Add a little salt to the ice and to the water; note again.

Maximum Density of Water.

11. Notice that ice floats in water. Close in the air-gas flame, soften and blow a small bulb on the end of a glass tube. Fill the bulb with water and put it in a mixture of ice and salt. Observe bulb burst.

12. Fill a flask with mixture of ice and water, fit in neck well-fitting cork with long narrow tube till water stands at a certain height in tube. Observe how it sinks as the ice melts.

13. Cool a flask in melting ice; fill it full with ice water (the water from melting ice), fit in cork with tube, well fitting till liquor stands in tube. Allow to get warm. Notice shrinking followed by expansion. Repeat the experiment, and observe the temperature of the water when its volume is least; show that the temperature is + 4° C. (39·2° F.).

Conduction in Solids.

14. Wrap a piece of paper smoothly around a brass tube (S. A. 24) and hold in air-gas burner. The paper is not scorched. Wrap the paper around a wooden rod of the same size, and heat; the paper is scorched.

15. Twist together at one end an iron and a copper (H. A. 5) wire. At about four inches from the joint fasten on both with beeswax a marble. Heat the joint in an air-gas flame. Notice that the marble on the copper is the first to fall.

16. Place a cylinder of metal (H. A. 7) on the air thermometer (H. A. 6). Notice height of liquid in stem. Heat copper cylinder (H. A. 7) in boiling water, dry it and place it on the first cylinder. Wait two minutes. Note the depression. Remove the cylinder and restore the temperature. Perform the same experiment with other metal cylinders, always using the same copper one as a heater. Notice the difference of depression with different metals. Cut cylinders of wood, cork, &c. and show that they arrest nearly all the heat.

17. Make a short coil of stout copper wire (H. A. 5), $\frac{1}{8}$ inch internal diameter. Pass it over the wick of a candle without touching the wick. The candle is extinguished.

18. Turn on but do not light a gas jet. Hold over it a wire gauze, and light the gas above the gauze. Notice that the flame does not strike through.

Conduction, Liquids.

19. Put a piece of ice in the bottom of a long test tube, weight it down with a piece of lead. Add water above. Hold obliquely and boil the water over an air-gas flame without melting the ice.

20. Set the flat part of the air thermometer (H. A. 6) perfectly horizontal. Clamp the flask (H. A. 6) bottom downwards, close to and exactly parallel with the top of the air thermometer. Leave an interval of about $\frac{1}{10}$ inch. Fill the space between the two in succession with water, alcohol, mercury, turpentine. Notice the height of the water in the stem. Pour a known quantity of water of a known temperature into the upper flask, and note the depression which occurs in a given time when various liquids are between the glass faces.

Conduction, Gases.

21. Examine shadow of red-hot poker. Notice that the heating of the air as exhibited by its refraction extends a very little way downwards, showing the air is a bad conductor.

22. Place a little lime in the palm of the hand and bring the point of the hot poker upon it. The air amongst the lime refuses to conduct, and the hand is not burnt.

Convection.

23. Heat over small flame a round-bottomed flask full of water. Throw into the water some solid colouring matter, like cochineal, aniline dye, litmus, &c. Notice how the hot and coloured water ascends.

24. Fasten the end of a candle on to a plate and light it; surround the candle with water. Place over the candle a cylindrical glass shade. Notice the extinction of the candle. Repeat the experiment and introduce down the centre of the cylinder a cardboard diaphragm. Notice that the candle continues to burn. Hold some smouldering brown paper near one side of the cardboard, and notice the direction in which the smoke moves.

Heat Quantity. Heat Tension and Temperature.

25. Compare two glass cylindrical vessels in their capacity for water. Compare equality of level of water with equality of temperature. Compare quantity of water with quantity of heat. Compare alteration of level by addition and withdrawal of equal quantities of water with alteration of temperature by addition and withdrawal of heat. Compare sectional area or capacity for water with capacity for heat. Notice pressure on bottom or on any surface at a given depth is proportional to the depth. Deduce that heat tension or temperature is only then proportional to heat quantity when capacity for heat is the same at all temperatures, &c.

26. Heat equally (to about 150° C.), in an oil bath, the metal cylinders (H. A. 7) fastened to thin wires. Lay them simultaneously on a cake of beeswax $\frac{1}{4}$ inch thick on retort stand. Notice the order of falling through of those which do so, and the depth to which the others sink.

27. Compare in 25 and 26 unit of heat quantity with unit of water quantity.

Specific Heat.

28. Or ratio between difference of heat quantity in a body between any two temperatures, and the difference of heat quantity of the same weight of water between the same two temperatures. Or in any equal range, assuming heat capacity of water is the same at all ranges.

29. Boil an iron 1 lb. weight, with string attached, in water. Wipe quickly dry and plunge in 1 lb. of water in a beaker glass at the air temperature. Move the weight about and find the temperature common to the two. Neglect cooling effect of glass. Let T_1 be temperature of iron ($= 100°$ C.). Let T_2 be temperature of water. Let T_3 be temperature of both. Then—

$$\frac{\text{Capacity for heat of iron}}{\text{Capacity for heat of water}} = \frac{T_3 - T_2}{T_1 - T_3},$$

$$\text{Or specific heat of iron} = \frac{T_3 - T_2}{T_1 - T_3}.$$

Confirm this by taking unequal weights and any other temperatures. Example, 5 ounces iron at 90° C., and 6 ounces water at 60° C. Let T_3 be the resulting temperature—

$$\text{Specific heat of iron} = \frac{6}{5} \cdot \frac{T_3 - 60°}{90° - T_3}.$$

Use differential air thermometer (6), show that 1 lb. of water which was at the atmospheric temperature, and has been heated by contact with 1 lb. of iron at 100°, is not so hot as the 1 lb. of water which was at 100° and has been cooled by contact with a pound of iron at the atmospheric temperature. Pour the water in the two cases into beaker glasses (H. A. 8), and plunge in the two air thermometer bulbs.

30. Shake up known weights at known but different temperatures of water and mercury, water and turpentine. Confirm by shaking up mercury and turpentine. The relative capacities for heat are inversely as the weights, and inversely as the range of change of temperature.

31. Weigh exactly a beaker glass nearly full of finely broken glass at the ordinary temperature. Pour into this hot water of known temperature, stir up with the thermometer and observe the temperature. Drain the thermometer into the glass and weigh. Let

W_1 be weight of glass at temperature T_1
W_2 be weight of water added at temperature T_2
Resulting temperature T_3

$$\text{Specific heat of glass} = \frac{W_2}{W_1} \times \frac{T_2 - T_3}{T_3 - T_1}$$

This should be about $0 \cdot 19$ or $0 \cdot 2$.

32. Introduce this correction into the calculation of the results in 30 as follows: Add to the weight of the water $0 \cdot 2$ times the weight of the glass. Thus using cold water and beaker and hot mercury.

Let w_1 weight of beaker glass at		-	T_1
,, w_2 ,, water	,,	-	T_1
,, w_3 ,, mercury	,,	-	T_2
Resulting temperature	-	-	T_3

$$\frac{w_2 + w_1 \times 0 \cdot 2}{w_3} \times \frac{T_3 - T_1}{T_2 - T_3} = \text{specific heat of mercury.}$$

33. Assuming that the capacity for heat of copper is the same at all temperatures ($= 0 \cdot 095$). Find heat of a coal fire as follows:— Weigh beaker (w_1), weigh water in beaker (w_2) at T_1. Heat copper ball in fire till it is as hot as the fire. Take it out and immediately plunge it in water. Move it about till temperature of the two is constant (T_2). Weigh all together and deduce weight of copper w_3. Let the heat of copper at first be T_3.

$$\text{Sp. heat of copper} = 0 \cdot 095 = \frac{w_2 + w_1 \times 0 \cdot 2}{w_3} \times \frac{T_2 - T_1}{T_3 - T_2}$$

$$\therefore T_3 = \frac{w_2 + w_1 \times 0 \cdot 2}{0 \cdot 095\, w_3} (T_2 - T_1) + T_2$$

One may assume that the tongs or hook employed in taking the ball out of the fire gets about as hot as the water. Employ also a lump of glowing coke out of a coke fire.

Let the heat unit be the quantity of heat necessary and sufficient to raise 1 grain of water at 0° C. to 1° C.

Look at the question in this way:—w_3 grains of copper fall from $x°$ to $T_2°$, that is through $(x - T_2)°$ C., and heat $(w_2 + w_1 \times 0 \cdot 2)$ grains of water from $T_1°$ to $T_2°$, that is through $(T_2 - T_1)°$ C. The w_3 of copper accordingly give out $(w_2 + w_1 \times 0 \cdot 2)(T_2 - T_1)$ heat units. Therefore 1 grain of copper falling through 1° would only give out

$$\frac{w_2 + w_1 \times 0 \cdot 2}{w_3} \quad \frac{T_2° - T_1°}{x° - T_2°}$$

heats units. Now 1 grain of water sinking through 1 degree gives out 1 heat unit. Therefore, specific heat of copper ($= 0 \cdot 095$) = the above. Thence deduce $x°$.

Latent Heat (a) of Water.

34. Weigh a beaker glass w_1. Put some broken ice into it, allow to stand, drain off any melted ice. Wipe the outside and quickly weigh. Let weight of ice be w_2. Pour into the ice about twice its weight of hot water, nearly boiling, of temperature T_1, stir up with

thermometer. Observe the temperature T_2, when all the ice is melted: drain the thermometer and weigh. Let the weight thence deduced of the water added be w_3. Then w_3 grains of water have sunk from T_1 to T_2 or through $T_1 - T_2$ degrees. Therefore, $w_3 (T_1 - T_2)$ heat units have been given out. These have melted w_2 of ice and heated w_2 of ice-cold water and w_1 of ice-cold glass from 0° to T_2, in doing the latter two (heating up water and glass) they have employed $(w_2 + w_1 \times 0 \cdot 2)\ T_2$ heat units. All the rest of the heat, namely, therefore, $w_3 (T_1 - T_2) - (w_2 + w_1 \times 0 \cdot 2)\ T_2$ have been employed in simply melting the w_2 of ice. To melt 1 grain of ice therefore—

$$\frac{w_3 (T_1 - T_2) - (w_2 + w_1 \times 0 \cdot 2)\ T_2}{w_2} \text{ heat units}$$

are necessary. This should be found about 79. That is, seventy-nine times as much heat is required to melt a grain of ice as is required to heat a grain of water through a range of 1° C. Otherwise a grain of ice put into a grain of water at 79° will just succeed by melting to bring the whole two grains to 0° C. The same of course is true of any other proportional quantities.

Deduce Specific Heat of Metals by means of Latent Heat of Water, as follows:

35. Line a cup with flannel. Scoop a smooth round hole out of a lump of ice; wipe the whole dry; weigh flannel, cup, and ice together. Quickly wipe and place in the hole one of the weighed metal cylinders (H. A. 7) which has been heated in boiling water. In ten or twelve seconds take out the metal, wipe out the water, and weigh again. Let the loss in weight of the ice by melting be in grains w^1. Let w_1 be the weight of the metal. Then $w^1 \times 79$ is the number of heat units given out by w_1 of the metal in sinking through 100° C. Therefore $\frac{w^1}{w_1} \times 0 \cdot 79$ is the number of heat units given out by 1 grain of the metal in sinking 1° C. Since 1 grain of water sinking 1° C. gives out 1 heat unit. The specific heat of the metal is—

$$\frac{w^1}{w_1} \times 0 \cdot 79.$$

Try with various metals.

Latent Heat of Steam.

36. Weigh on a pad of flannel a beaker glass or flask (w_1). Weigh in the glass some water (w_2) at the ordinary temperature T_1. Fasten into a flask through a cork in its neck a wide glass tube having a narrow end, bent twice at right angles. Heat the water in the flask till it boils briskly, and all the water condensed in the tube is driven over. Hold, in flannel, the cold water so that the narrow part only of the steam tube is in the water. After one or two minutes withdraw, take temperature, and weigh. Let temperature be T_2 and increase of weight be w_3. Then w_3 is the weight of the condensed steam. Then w_3 grains of steam at 100 have condensed to water at 100, and this water has sunk to T_2. In the latter process $(100 - T_2)\ w_3$ heat units have been employed. The actual heating effect, however, has been to heat $w_2 + w_1 \times 0 \cdot 2$ of water from T_1 to T_2, or $(w_2 + w_1 \times 0 \cdot 2)$ $(T_2 - T_1)$ heat units have been expended in this. Therefore—

$$(w_2 + w_1 \times 0 \cdot 2)\ (T_2 - T_1) - (100 - T_2)\ w_3 \text{ heat units}$$

were given out by the mere condensation without cooling of the w_3 grains of steam. To condense without cooling 1 grain of steam accordingly—

$$\frac{(w_2 + w_1 \times 0 \cdot 2)\ (T_2 - T_1) - (100° - T_2)\ w_3}{w_3}$$

heat units are required. The number should be found nearly 537.

Otherwise one grain of steam in condensing would heat 537 grains 1 degree, that is, give out 537 heat units and still be at 100° C.

37. The specific heat of turpentine can be found when we know the latent heat of steam. For if w_1 be weight of glass containing w_2 of turpentine both at T_1, and if we pass steam in for some time and find that the temperature, is raised to T_2 and that w_3 grains of steam have been condensed, then we know that in the condensation $w_3 \times 537$ heat units have been given out, and in the sinking from 100 to T_2 there were evolved $(100 - T_2)\, w_3$ heat units, so that in both processes there were evolved $w_3\,(637 - T_2)$ heat units; these have heated w_1 of glass from T_1 to T_2 and w_2 of turpentine from T_1 to T_2. For the former $(w_1 \times 0 \cdot 2)\,(T_2 - T_1)$ heat units were necessary. Therefore for the latter $w_3\,(637 - T_2) - w_1 \times 0 \cdot 2\,(T_2 - T_1)$ were required. So to heat 1 grain of turpentine through 1° C. there are required—

$$\frac{w_3\,(637 - T_2) - w_1 \times 0 \cdot 2\,(T_2 - T_1) \text{ heat units}}{w_2\,(T_2 - T_1)}$$

which is the specific heat.

Latent Heat of other Vapours.—Turpentine.

38. Boil turpentine in the flask (36) previously dried. First find boiling point of turpentine T_1. Then put in cork and tube; pass the vapour of turpentine into weighed glass w_1 containing weighed water w_2, both at temperature T_2. After a time suppose the temperature to be T_3 and the weight of condensed turpentine to be w_3. Then the heat work done was to raise w_1 of glass and w_2 of water from T_2 to T_3. The heat units concerned are therefore $(w_2 + w_1 \times 0 \cdot 2)\ (T_3 - T_2)$. These units have been derived from the cooling of the w_3 grains of turpentine from T_1 to T_3, or ($w_3 \times$ sp. heat of turpentine) $(T_1 - T_3)$ heat units, and from the condensation of w_3 grains of turpentine. Therefore—

$$\frac{(w_2 + w_1 \times 0 \cdot 2)\,(T_3 - T_2) - w_3 \times \text{sp. heat of turpentine} \times (T_1 - T_3)}{w_3}$$

is the number of heat units given out by the condensation without cooling of 1 grain of turpentine, that is, the latent heat of turpentine vapour.

Heat absorbed or evolved by Change of State.

39. Surround with water of the same temperature the two bulbs of the differential air thermometer 6. Dissolve in the water around one bulb in succession, sugar, nitre, sulphate of sodium, salt, &c., and observe the absorption more or less of heat.

40. Remove the liquids, dry the bulbs from Experiment 39, and let water, alcohol, and ether in succession drop upon and evaporate from one of the bulbs. Observe the absorption of heat.

41. Place a small cup of water, a watch glass on flannel. Stand in it with a little wax a lady's thimble. Put some ether into the thimble and blow over it with a pair of bellows having a tube fastened to the nozzle. The water will freeze.

42. Notice the liberation of heat when a cold body condenses by contact the steam from a kettle. Refer to Experiments 34-38.

43. Dissolve sulphate of sodium (H. A. 11) in water at a blood heat until the water is saturated. Pour off the clear into a clean beaker and cover carefully. Allow to cool; stand in water. Surround the two bulbs of the air thermometer 6 with basins. Into one pour water; into the other pour the solution of sulphate of sodium. The latter will solidify and give out heat.

44. *Freezing Mixture.*—Show that by mixing powdered ice or snow and salt a temperature of — 22° C. can be got. With chloride of ammonium and ice a temperature of — 16° C., with sulphate of sodium

and ice a temperature of $-0{\cdot}7°$ C., and with nitre and ice a temperature of $-3°$ C. Try as many other salts as are at disposal, using three or four parts by weight of ice to one of salt. Freeze distilled water in test tube when surrounded by one or other of these freezing mixtures. Notice that the temperature should be 0° C. So correct the thermometers.

Behaviour of Salt Solutions on Loss of Heat.

45. Make boiling saturated solution of nitre. Observe the boiling point is above 100° C. Let it cool to atmospheric temperature. Notice the separation of the salt. Pour off the clear into a flask and cool it to 0° in melting ice ; notice further separation of the salt. Pour off into another flask with thermometer, and surround with freezing mixture of table salt and ice. Still more salt separates, and the temperature falls to $-3°$ C., whenceforth it remains constant and an opaque cryohydrate solidifies. Remelt a part of this, weigh about 20 grams of it in a weighed basin, and evaporate to dryness and weigh again. There should be found about 11·2 per cent. of salt.

Take a dilute solution of nitre (about 5 of nitre to 95 of water), cool in a freezing mixture of ice and table salt with thermometer. Notice the temperature at which ice separates is below 0° C. Go on cooling, more ice separates, and the temperature falls till the temperature reaches $-3°$ C., when it ceases to fall further, but the opaque cryohydrate begins to be formed. Pour off the unfrozen into another flask and put into the freezing mixture. Notice that it all solidifies at $-3°$. Melt a portion and weigh about 300 grains in a weighed basin, evaporate to dryness and weigh again. The percentage of salt formed is the same as before, namely, 11·2.

Hence generalise that the lowest temperature attainable by the use of a salt and ice as a freezing mixture is the melting or solidifying point of the cryohydrate of that salt.

Vapour Tension.

46. Make a barometer out of a tube 33 inches long and $\frac{1}{8}$ inch internal diameter by filling it with mercury and inverting into a cup of mercury. Pass over the barometer tube a wider glass tube fitted below around the barometer tube by a water-tight cork. Pass up into the barometer three or four drops of water. Notice the depression of the mercury due to the vapour tension of the water. Pour hot water between the tubes, and slightly inclining the two heat the outer one by passing to and fro beneath it an air-gas flame till the water in the outer tube begins to boil. Notice that then the level of the mercury inside is the same as that out. Repeat the experiment, using alcohol in the inner tube, note the greater depression at first, and observe that the water in the outer tube need only be heated to 78° C. for the mercury to stand at the same height inside and out. With ether the initial depression is still greater, and the requisite temperature is only 36°.

Boiling: Distillation.

47. Fit neck of a small flask with cork carrying a tube 2 feet long, bent once at right angles at about 3 inches from one end, and again at an angle of 135° at 18 inches from the other. Through the cork pass air-tight also a thermometer. Over the far end place a small flask surrounded by ice. Place water in the first flask and heat to boiling. Observe that the thermometer stands at 100° whether the bulbs be in the water or the steam. Repeat the experiment with alcohol and ether, but in these cases place the flask containing the liquid in a basin of water which is heated by the flame. Notice that the alcohol boils at 78° C. and the ether at 38°. Observe that these temperatures are the same as those in Experiment 46.

Rectification.

48. Dilute some alcohol with its own volume of water and distil half over as in 47. Bend a long tube in a V shape, fix in a vertical plane, and pour from the undistilled part when cold enough to fill both limbs of the V tube one third full. Pour as much of the distillate down one limb and notice that the vertical heights of the surfaces of the liquids in the two limbs are unequal, the liquid in the limb containing the distillate standing the highest.

Boiling under lessened Pressure.

49. Get a very well fitting, soft, long, and sound cork to fit the neck of a 4-oz. round-bottomed flask. Boil water in the flask till all the air is expelled. Remove burner, and cork up the flask as nearly at the same instant as possible. Turn the flask over and pour cold water on the top. Also immerse the corked flask in cold water and observe in both cases the ebullition under diminished pressure.

Nature of Surface.

50. Show that if water is just beginning to boil in a glass flask platinum wire, chips of glass, pieces of charcoal, and so on, cause increased boiling for the moment.

Spheroidal State.

51. Heat a silver or plated tea spoon in the air gas flame, almost red hot; turn out the gas and immediately drop into the spoon some hot water or cold alcohol or ether. Notice the spheroidal state maintain itself until the spoon cools, when there is contact and a burst of vapour.

52. Mix a little soap solution in a large vessel (a pail) of water. Heat red hot the copper ball (H. A. 10) and plunge it in. Notice that the ball does not touch the water, a film of water vapour intervening. Take it out, it is still red hot; plunge it in clean water and it is quenched.

Regelation.

53. Press together two pieces of ice under warm water. Notice how they stick together. Support a block of ice at its two ends, so as to make a bridge. Pass over this a silk thread and an equally thick copper wire, at all four ends hang a four-pound weight. The copper will cut through the ice, the silk will not. Though the copper wire in an hour or so will cut right through the ice, the severed faces will stick together above the wire perfectly.

Radiant Heat.

Law of Reflection.

54. Blacken the bulb of the air thermometer (Ex. 5) with lamp black. Arrange the two tinned tubes (L. A. 10) in a horizontal plane at right angles to one another. Fasten in a vertical plane a tinned iron sheet making 45° with each as close as possible to their contiguous ends. Place black bulb of air thermometer at free end of one tube, and a large air gas burner or red-hot copper ball at the free end of the other. Notice the expansion of the air in the thermometer.

55. Place two concave spherical mirrors (best silvered on the concave side) opposite to one another, 3 feet apart (the mirrors should not be less than 6 inches diameter), and having their axes exactly in the same straight line. In the principal focus of the one place a candle flame. In the principal focus of the other place the blackened bulb of the air thermometer. Notice the heat given to the bulb. Show that this effect is not stopped by screening off by a 2-square-

inch screen the direct radiation from the candle to the bulb, but it is completely stopped by placing a piece of cardboard, as large as one of the mirrors, either between the candle and the nearest mirror to it, or between the bulb and the nearest mirror to it.

56. Replace the flame by a red-hot copper ball; also by a flask of boiling water.

Theory of Exchanges.

57. Replace the source of heat in 55 and 56 by a flask containing a freezing mixture. Notice the bulb of the air thermometer is cooled. The bulb is now the source of heat relatively to the freezing mixture.

Refraction.

58. Employ sun's light, if possible. If not, use lantern. Obtain parallel beam: focus light, and show that heat is also focussed to the same place by putting the black bulb of an air thermometer there. Fill cell (L. A. 18) with bisulphide of carbon (H. A. 11), add iodine till all the light is stopped. Notice that the heat still passes through, and is focussed in the same place.

Radiation. Nature of Surface.

59. Employ tin-plate cube (H. A. 12). Smoke one face next to tube with turpentine flame, till it is thickly covered with lampblack. Paste white paper on another side. Rub a third with coarse sand-paper. Place the cube on a retort stand (S. A. 26), fill with water, and heat over an air-gas burner till it boils. Protect the flame by a tin-plate chimney. Place black bulb of air thermometer in succession at equal distances from the four faces, beginning with the bright one, and keep it there for the same time. Notice the different amounts of depression in the air thermometer. Return to the bright face, and having let the liquid of the thermometer rise, paint the bright face with a solution of isinglass (L. A. 23) in water. Observe that as soon as the water is driven off by the heat the thermometer shows increased radiation from the covered surface.

60. Take four bright tin saucepans (H. A. 13), cover two thickly all over with lampblack; or glue some cloth over them; or paint them over with solution of isinglass, and dry. Fill one of the untouched pans and one of the covered ones equally with hot water of the same temperature. Hang the two up in a cool place. Fill equally with cold water the other two saucepans and hang them for the same time at the same distance above an iron plate, supported on a retort stand and heated by an air gas burner. After half an hour notice (*a*) that of the first pair the water in the bright saucepan is the hottest, (*b*) of the second pair that in the bright one is the coolest. Prove by differential air thermometer.

61. Paste a piece of tin foil on a piece of cardboard and toast the covered side before the fire or hold a red hot poker over it. Notice how by reflecting the heat the foil protects the paper.

Dew.

62. Coat with silver outside (L. A. 14) about 2 inches of the bottom of a test tube. Fit cork. Through cork pass (*a*) a thermometer, (*b*) a tube reaching to the bottom and bent horizontally outside the cork, (*c*) a straight tube. Place a glass screen between the body and the tube. Fasten nozzle of bellows to end of bent tube. Put two inches of ether into the tube and fit in cork. Work the bellows so that air bubbles through the ether. Notice how thermometer sinks. At last dew is deposited on metal surface, Mark temperature. Stop

bellows. Let dew vanish; mark temperature. Do this several times and take the mean of the readings. Notice the reading of another thermometer in the air. Difference of readings is greater according as the air is drier.

Diathermancy and Athermancy.

63. Repeat experiment 58. Substituting in the cell (*a*) a slab of glass, (*b*) water, (*c*) a strong solution of alum.

Chemical Heat. Animal Heat.

63. Repeat experiments 1 in Light, to show that the heat of flames is due to oxidation, generally of hydrogen and carbon. Blow air from the lungs into a bottle. Notice the deposition of moisture. Shake up with lime water, and notice formation of carbonate of calcium.

Heat of Friction.

65. Notice striking of a match, explosion of a percussion cap, warming hands by rubbing, scorching of wood by friction. Hammer leaden bullet flat and lay it upon flat part of air thermometer (H. A. 6). Notice heating effect. Repeat experiments of Sound, 13. Blow air from bellows upon dry black bulb of air thermometer. Notice heating effect.

SUBJECT VIII.—APPARATUS AND MATERIAL FOR ELEMENTARY EXPERIMENTS IN HEAT.

1. A pound of soft solder. Pieces of zinc. Make soldering solution by saturating some hydrochloric acid with pieces of zinc. Moisten with this solution and heat the metals to be soldered together; melt on a little of the solder, and hold the metals together till the solder is set.

2. Close a piece of glass tubing at one end, draw out the other end so as to make a narrow neck. Fill up to neck with water, and seal off in air-gas flame so as to leave as small a bubble of air as possible. (Closing a tube by fusion of the glass is called hermetically sealing it.)

3. Round table-stand adjustable for height.

4. Ice.

5. A mercurial thermometer graduated on stem from $+160°$ to $-30°$ C. 2 ft. thick copper wire. 1 square foot iron gauze.

6. Take one of the 2 oz. round flasks of L. A. 5, dry it, warm it; heat the bottom till it softens over an air-gas burner; press it on a flat surface of charcoal till the flat part is about as large as half-a-crown. Do another in the same way. Make of one an air thermometer, as in 5.

7. Short cylinders of as many metals as possible, say iron, copper, zinc, tin, lead, bismuth. Each $\frac{3}{4}$ inches diameter and $\frac{1}{2}$ inch thick.

8. A nest of small beaker glasses.

9. A set of grain weights. And a balance able to turn with one grain when loaded with 10,000 grains.

10. A copper ball about 3 lbs. weight, with copper eye and iron hook. Fire tongs.

11. Sugar, salt, nitre, sulphate of sodium, chloride of ammonium, $\frac{1}{2}$ oz. iodine, 1 lb. bisulphide of carbon.

12. Solder together, to form a cube, six squares 5 in. each of tin-plate (L. A. 10), leaving a hole 1 in. diameter in one, to which solder a tin-plate tube 1 in. diam., 2 in. long.

13. Four pint bright tin saucepans with lids.

SUBJECT IX.—ELEMENTARY EXPERIMENTS IN ELECTRICITY AND MAGNETISM.

N.B.—*The numbers in brackets refer to the list of apparatus and material.* (S. A.) *signifies sound apparatus, p.* 10 ; (L. A.) *signifies light apparatus, p.* 19 ; (H. A.) *signifies heat apparatus, p.* 30 ; *and* (E. A.) *signifies electrical apparatus, p.* 39.

Frictional or High Tension Electricity.

General.

Experiments in frictional electricity succeed best in the winter, when the atmosphere is, on the average, drier. On frosty days best. A brazier or chauffer is very useful, or a brisk coal or coke open fire. A gas reflecting stove is excellent, where the products of combustion are carried away. Apparatus for frictional electricity must be perfectly dry, and should be heated by radiant heat till quite hot. To stop draughts, which carry moisture, the apparatus should be placed between the source of radiant heat and a screen reaching to the ground. No pains should be spared to ensure continual dryness, as the entrance of a few people into a room in which experiments have perfectly succeeded will in a few minutes cause failure unless the dryness is maintained.

Approach and Repulsion.

1. Balance lath (E. A. 3) upon the inverted bottom of a round flask (L. A. 5), which may stand on its neck, or the neck may be placed in or over the neck of a wine bottle.

Rub smooth face of resin on hot dried flannel, and hold to one end of lath. Notice approach.

Rub dry and hot sheet of brown paper with clothes brush (E. A. 5), fold and bring round side to end of lath. Notice approach.

Heat mahogany board (E. A. 12), and heat foreign-post paper (E. A. 6), rub the paper on the board with bottle caoutchouc (E. A. 7). Pick the paper off. Notice crackling and sparks in dark room. Lay it on other side of board, also on wall. Notice how it clings : also attract lath.

Arm two fingers with pieces of vulcanized caoutchouc tubing. Draw silk ribbon between. Observe ribbon cling to wall, also attract lath. Draw collodion film (E. A. 15) between dry fingers, and observe attraction to lath.

2. Spread amalgam (E. A. 10) upon silk rubber (E. A. 9), warm thoroughly, and use while warm. Close one end of thick glass tube (S. A. 26) two feet long. Heat thoroughly. Rub amalgamed silk on glass till crackling is heard. Show how electrified glass attracts feathers, gold leaf (E. A. 11), lath, &c. The silk rubbers improve very much by use.

3. Rub stick of shellac (E. A. 17) with dry flannel (E. A. 1), and repeat on substances used in Experiment 2.

4. Rub stick of sulphur (E. A. 20), and repeat as in Experiments 2 and 3.

5. Excite glass with amalgamed silk, also sealing-wax with flannel, and place each in succession on wire stirrup (E. A. 19), and hang up by thread. Notice how each moves towards the hand when held near.

6. Show that shellac or sealing-wax rubbed with flannel is attracted by glass rubbed with amalgamed silk.

Two Kinds.

7. Show that sealing-wax rubbed with flannel is repelled by sealing-wax rubbed with flannel (one piece on wire stirrup), and that glass rubbed with amalgamed silk is repelled by glass rubbed with amalgamed silk. Show that sulphur rubbed with flannel is repelled by wax rubbed with flannel.

8. Excite thin sheet of writing paper as in Experiment 1 on hot mahogany board with bottle caoutchouc. Cut it into strips as it lies with a sharp knife, leaving a band at one end, hang it from a thread fastened to a bent pin. Notice how the strips repel one another. Bring near them a glass rod excited with amalgamed silk. Observe general repulsion. Observe attraction to excited sealing-wax.

9. Touch top of electroscope (E. A. 22) with excited sealing-wax, sulphur, glass, &c., in succession, and observe increased divergence or collapse of leaves.

10. Heat glass very hot, rub with fur, and notice that the glass acquires the same kind of electricity as sealing-wax rubbed with flannel. Rub sealing-wax with gun-cotton (E. A. 23), and notice that it becomes electrified as wax rubbed with flannel.

Conduction and Isolation.

11. Fasten one end of a fine copper wire (E. A. 24) five yards long through the hole in the electroscope; make a loop at the other end, place the loop over the glass tube, and having excited the tube with amalgamed silk, let the loop slide along the tube. Notice divergence of leaves. Use sealing-wax and flannel as above. Also replace wire by cotton thread, dry silk thread, and wet silk thread.

12. Hold metal candlestick or poker in sheet of vulcanized caoutchouc, and beat it with flannel: show that it becomes electrified.

13. Make isolating stool. Varnish (E. A. 25) four strong glass tumblers. Place on the top the mahogany board.

14. Stand on stool (Experiment 13), touch electroscope with finger. Let the coat be struck by another person with the fur skin.

15. Paste tin foil (L. A. 11) or Dutch metal (E. A. 11) on both sides of cardboard. Cut out round discs of various diameters and fasten on to ends of sticks of shellac or thin varnished glass tubes. (Proof planes.)

16. Use proof plane by touching in succession the bodies electrically excited in experiments 1—7, and then, touching the electroscope, determine which are $+^{ly}$ and which $-^{ly}$ electrified. Show that the proof plane when neutral will cause a partial collapse of the leaves however excited: that when electrified with the opposite kind the proof plane may also produce partial collapse, total collapse, or the latter followed by divergence.

Induction.

17. Bring electrically excited body near to electroscope. Observe divergence of leaves; followed by collapse on withdrawal.

18. Attach, by a copper wire, the electroscope to one of the balls (E. A. 26). Excite glass rod with amalgamed silk, and bring it near the ball. Arm finger and thumb with stalls of vulcanized caoutchouc tubing and with them remove wire from electroscope. Show that the leaves are diverged with + electricity. Perform analogous experiment with shellac and test electricity.

19. Hence use of induction test for kind of electricity. Charge, by contact, the electroscope by means of proof plane with + or — electricity by using glass (with amalgamed silk) or sealing-wax (with

flannel). Bring near electroscope the various bodies excited as in experiments 1—7. Observe whether they are $+^{ly}$ or $-^{ly}$ excited by obtaining increased divergence. Notice that a neutral body when near electroscope causes partial collapse.

20. Put the hand on electroscope. Approach $\pm$ electrified body. Then remove the hand. Then remove the electrified body. Notice that the leaves diverge with $\mp$ electricity.

Local Analysis.

21. Repeat experiment 18, but remove the wire from ball instead of from electroscope; test electricity in ball and show that it is —. Show by proof plane that the electricity in the ball is + if shellac is used.

22. Place the two balls (E. A. 26) in contact with one another. Bring excited glass near one, remove the other, then the glass. Show that the ball nearest to the glass has $-^{ve}$, the other $+^{ve}$. Show the converse with shellac.

23. Bring the excited glass near one side of an isolated ball (E. A. 26), touch the side nearest to glass with proof plane. Show that the plane becomes $-^{ve}$. Touch other side; show that the plane becomes $+^{ve}$. Touch the ball momentarily anywhere with the hand: then remove the glass and show that the whole ball is $-^{ve}$. The converse with shellac.

24. Place the excited rod over the table or near the wall: touch the wall with the proof plane and show that the plane becomes $-^{ve}$.

25. Support metal tea-tray on varnished tumblers. Just over a jet of unlighted gas fasten two wires, one to the earth and the other to the tray. Let there be an interval of about one tenth of an inch between the wires. Excite hot brown paper with clothes brush and lay it immediately on the tray—the gas will be lit. Put it out and turn it on again. Remove the paper, the gas will again be lit.

Electrophoros.

26. Arrange as in 25. After putting on the sheet of excited paper, touch the tray with the proof plane and show by the electroscope that it is negatively charged. Touch the tray with the finger. Lift the paper and show that the tray is $+^{ly}$ charged.

27. Fasten a stick of sealing-wax to the middle of a sheet of tin plate having smooth edges. Beat sheet of vulcanized caoutchouc with fur. Place tin plate, holding it by the sealing wax, upon the vulcanized sheet; touch the plate with the finger, lift and obtain spark to finger.

Distribution.

28. Place a round disc of tin plate on an isolator (a varnished glass tumbler), charge it by excited glass rod or shellac. Touch it in succession in the middle and the edge with a proof plane and compare by electroscope the amounts of electricity communicated.

29. Isolate tin saucepan (H. A. 13), electrify the inside by repeated charges from a proof plane. Notice that a charge cannot be got from the inside unless the top of the proof plane projects out during contact. Charges can be got from the outside, especially at the edges.

30. To show that such distribution depends upon the induction with surrounding objects, hang a metal covered ball (E. A. 26) by an earth-connected wire close to the saucepan, inside it. The proof plane can now be charged by touching the inside of the saucepan. An opposite charge can be got from the hung ball.

Point Discharge.

31. Electrify shellac rod or glass tube. Pass twice rapidly from end to end on opposite sides, at a distance of a few inches, a sharp needle held in the hand and pointing at the excited body. Notice how completely the body is discharged.

32. Excite glass rod and let fall towards it a gold leaf. Notice how the leaf is kept up.

33. Fasten wire with a needle at the end to the $+^{ve}$ conductor of the electrical machine (E. A. 27). Feel the wind from the point and blow out therewith the flame of a candle. Notice the difference when the needle is fastened to the $-^{ve}$ conductor.

Electrical Machine.

34. Study and test electrical machine with and without earth connexion to one or other conductor. Repeat as many of the previous experiments as possible with the electrical machine, especially such as were difficult to obtain with the excited glass or shellac.

Condensation or Accumulation.

35. Fasten silk thread to two opposite edges of varnished glass plate. Lay earth—connected thin copper wire on table. Place sheet of tin foil on wire. Place the varnished glass plate, which should be about one inch larger all round, on the top of the foil. Place another piece of foil of the same size as the first on the glass. Pass another wire from the upper foil to the electroscope. Connect upper foil with the $+^{ve}$ conductor of the machine. Turn the machine till the leaves begin to stir. Remove the wire to the machine by means of the discharging tongs or other isolator. Gently lift the glass plate, with the tin foil on it, by means of the silk handles. Observe the leaves diverge.

36. Place mahogany board on varnished tumblers; end of earth connected copper wire on board, then foil, then glass, then foil connected with $+^{ve}$ conductor of machine, as in 35. After working remove earth wire. This may always be done with the unprotected fingers. Then remove wire to conductor. This may now be done with unprotected fingers. Lift up glass with upper foil. Test both foils and show that the upper is $+^{ly}$, the lower $-^{ly}$ electrified.

37. Repeat 35, with this difference, paste both foils on to the glass, fasten a tongue of foil from the lower foil round the edge of the glass. Roll the free end round a varnished glass tube, which is laid upon the margin of the glass. By rolling the tube to and fro the distance between the upper and lower foils is made lesser or greater. On working the machine until a spark passes from one to other foil, notice the increased loudness of the sound and brilliancy of the spark.

38. Charge electric jar (E. A. 29) by holding it in the hand and resting its knob against the $+^{ve}$ conductor, using the electric gauge (E. A. 30). Place the jar on the isolating stool, Ex. 36. Show by proof plane that there is free $+^{ve}$ electricity on the knob. Touch the knob with the hand, show that there is free $-^{ve}$ on the outside. Touch the outside; then there is free $+^{ve}$ again on the inside; and so on.

39. Charge jar and discharge it by discharging tongs (E. A. 28). Notice that a second and a third discharge can be obtained (residual charge).

Effect of Spark.

40. Put a pinch of gunpowder on a metal plate, earth connected. Charge a jar, connect its outer coating to the earth. By means of the discharger, let a spark pass from the inner coating into the

powder. The powder is scattered. Hang a metal ball from one end of the discharger by a piece of wet string, so as to decrease the conduction of the tongs. The powder will be ignited.

41. Arrange jars as a battery. That is, connect all their outer coatings with one another and the earth; all their inner coatings with one another and the $+^{ve}$ conductor of the machine. Employ the electric gauge (E. A. 30). Stretch between two weights a thin piece of platinum wire on a card. Connect one weight with the earth. By means of the discharger connect the other weight with the inner coatings. Notice deflagration of wire.

N.B.—When more than one jar is discharged it is safest to fasten the middle of the discharger to a long varnished glass tube.

42. Isolate all the jars but the last. Connect the outer coating of the last with the earth. Connect the inner coating of the first with the $+^{ve}$ conductor of the machine; the outer coating of the first with the inner of the second; the outer of the second with the inner of the third, and so on. Notice how quickly the battery is charged (cascade arrangement) and how imperfectly.

Nature of Discharge.

43. In a dark room illuminate the rotating coloured disc of the humming top (S. A. 17) by a spark from a jar, notice that the colours are seen distinct (duration of spark).

44. Study the light from point of needle attached to prime conductor in dark room. Also that from head of a pin. Boil a pinch of starch in water, add a crystal of iodide of potassium (E. A. 32). Moisten blotting paper with this solution, and hold the paper near the head of the pin. Notice coloration of paper (ozone).

45. Place a sheet of vulcanized caoutchouc on an earth-connected sheet of foil. Beat the caoutchouc with the fur-skin. Draw lines on the caoutchouc with the knob of a $+^{ly}$ charged jar. Place in a muslin bag a mixture of dry powdered red-lead and sulphur (E. A. 32). Shake over the caoutchouc. Notice the selective distribution of the two powders.

Relation of Heat to Electricity.

46. Hold a lighted match over a $+^{ly}$ charged electroscope, also over a $-^{ly}$ charged one, notice the discharging effect of the flame.

47. Heat iron ball (E. A. 33) white hot in fire: take it out on isolating hook (E. A. 33); show that at first it refuses to take a charge either of $+^{ve}$ or $-^{ve}$ electricity. As it cools, it first becomes chargeable with $-^{ve}$ and subsequently with $+^{ve}$ electricity.

48. Heat white hot and take out of fire, with conducting hook, the iron ball (E. A. 33), bring it in succession to the same distance above $+^{ly}$ and $-^{ly}$ charged electroscope. Show that at first at a certain distance it discharges both kinds. As it cools it retains longest its power of discharging the $-^{ly}$ charged electroscope.

Atmospheric Electricity.

49. Fasten a piece of paper to $+^{ve}$ conductor of machine. Hold needle towards it. Observe collapse and repulsion. Cover point of needle with finger. Notice repulsion and collapse cease.

50. Put the end of a long wooden rod in a varnished glass tube, or hold it in a sheet of vulcanized caoutchouc. Fasten thin copper wire to rod and electroscope. Fasten sponge dipped in alcohol to the top of the rod. Light the alcohol. Bring the flame over a point fastened to the prime conductor. Observe the leaves diverge.

51. Bring a large isolated conductor (a packing box) on the isolating stool in contact with the prime conductor. Stand near the isolated conductor, holding in the hand a wire just above a turned-on metal gas jet. Let someone take a spark from the prime conductor. A spark will, at the same instant, pass to the gas jet and ignite the gas.

Magnetizing Effect.

52. Lay a strip of tin foil on a sheet of varnished glass. Lay one piece of steel wire above and another below the foil, across it. Send several sparks from the battery along the foil. Notice the magnetization and test the polarity.

VOLTAIC OR CHEMICAL ELECTRICITY.

Magnetic Effect of Current on Iron Filings.

53. Set up three cells of a platino-zinc battery (E. A. 34). Connect poles by copper wire. Show that iron filings adhere to the wire.

Deflexion of Needle.

54. Make a magnet by rubbing one end of a two-inch long piece of steel ribbon on the N. and the other on the S. pole of a permanent magnet (E. A. 36, 37), slightly bend the strip in the middle and hang it from a thread horizontally. Mark the poles of the magnet. Set up battery as in 53. Connect poles by copper wire running N. and S. Hang the needle above and below the wire. Also while the magnet is hanging change the connexions of the wire with the battery. Notice the direction in which the magnet turns in the four cases.

Electro-Magnet.

55. Place a soft iron nail at right angles to the wire close to it, above it, and also below. By means of the magnet of 54 show that the nail acquires magnetism as the current is passing. From the nature of its polarity deduce that the effect of the current from the platinum pole is the same as the effect of the spark from the $+^{ly}$ charged jar in 52.

56. Wrap two yards of the copper covered wire (E. A. 35) into a hoop coil two inches in diameter. Flatten the hoop till it is about three quarters of an inch wide. Support it on clamps in a vertical plane N. and S. Hang the magnet, 54, in the middle of the coil by silk thread. (Galvanometer.) Fasten two ends of galvanometer wire to flexible wires (spirally wound) and to each of these fasten some metal, using different metals simultaneously. Dip the pairs of metals into different liquids, such as dilute acids, salt solutions, and alkalies, and from the deflexion of the needle deduce the direction of the current.

Current in Battery.

57. Set up the battery as above N. and S. Connect the poles. Test by hanging needle the direction of the current in the battery itself. Thence deduce direction of current of single cell throughout its whole circuit.

58. Make right-handed and left-handed helices as models. Make a flat spiral (in one plane) and show how it becomes a right or left-handed conical spiral according as its centre is pushed out one way or the other.

59. Wrap covered copper wire round a poker from end to end in a right-handed spiral, and attach ends to battery. Examine polarity of

poker, keeping connexions with battery the same, reverse the spiral. Reverse in both cases the battery connexions. Examine polarity in each case. Wrap the wire round the poker continuously from end to end and back again. Again examine polarity.

60. Make an electro-magnet out of a horse-shoe.

61. Cover four inches of glass tube three quarters of an inch in diameter with covered copper wire wrapped to and fro. Support it vertically and send current through the wire. Bend a piece of tinned iron into a cylindrical tube half an inch in diameter and notice how it springs into the glass tube.

Polarity of Coil.

62. Wrap a covered copper wire into a helix, bring the ends round inside the helix to the middle, then through the helix and through a flat cork. On one end fasten a piece of zinc and on the other a piece of copper. Float the whole on dilute sulphuric acid (1 : 12). Show that the coil floats N. and S. and that one end is attracted and the other repelled by the N. end of a magnet. Deduce from this that the polarity of the coil is the same as that of the induced magnet inside. Confirm this by examining the polarity of the coil of 61 and the polarity of a rod of iron placed inside it.

Attcration and Repulsion of Current.

63. Make two flat spirals of covered copper wire. Connect one end of one with one end of the other. Send a current through both. Notice that if the currents are going the same way in both, when they are laid flat on one another, they attract; if in opposite directions, they repel.

64. Make an open spiral of elastic wire. Hang it vertically. Let lower end just dip into a small cup of mercury which is in contact with one pole of battery. Connect the other end of the wire with the other pole. Notice the wire jump.

Chemical Effect of Current.

65. Amalgamate a piece of zinc (E. A. 34), place it in a beaker of dilute sulphuric acid. Place a sheet of copper near it. Notice that there is no action until the two metals are in contact either in the liquid or by metallic connexion outside. Observe bubbles of hydrogen rise from the copper. Let such a couple stand for a day or two and notice the solution of the zinc (as sulphate of zinc).

66. Electrolyse slightly acidulated water in apparatus (E. A. 38) by covering the platinum foils with acidulated water, filling two test tubes with the same, inverting over the foils, and connecting the copper wires with the poles of the battery. Let the test tubes be of the same diameter. Notice that twice as much gas is evolved from the $+^{ve}$ pole as from the $-^{ve}$. Examine the gases, show that the smaller volume is oxygen by removing it and introducing a glimmering splinter of wood. Show that the larger volume is hydrogen by igniting it. Repeat the experiment, mix the gases, and explode.

Polarization of Electrodes.

67. After electrolysing water, connect the platinum poles with the terminals of galvanometer, 56. Show that the needle turns in such a way as to show a current from the hydrogen to the oxygen.

Electrolysis.

68. Electrolyse various solutions of metallic salts (sulphate of copper, nitrate of silver, sulphate of iron, acetate of lead, &c.), avoiding chlorides, show that the metal separates at the $-^{ve}$ pole.

69. Employ glass cell (L. A. 18). Form a porous diaphragm transversely down the middle by stitching together several thicknesses of blotting paper. Pour in, on both sides of the paper, solution of sulphate of soda, coloured with litmus. Colour one solution red by a drop or two of dilute acid. Into the red solution put the $-^{ve}$ electrode, into the blue the $+^{ve}$. Notice that the red becomes blue, and the blue red. Reverse the poles and invert the effect.

MAGNETISM.

Directive Polarity.

70. Take off keeper of horseshoe magnet and hang it vertically by a thread. It comes to rest nearly N. and S. Call the pole towards the N. the north-seeking, that towards the S. the south-seeking pole. Make a magnet out of a strip of steel as in 54. Show that this when hung up also points N. and S. Mark its poles as above, and show that like named poles attract and unlike repel one another.

71. Scatter iron filings over the magnet and notice the accumulation at the ends.

Distribution of Magnetism in Magnet.

72. Heat 4 inches of the steel ribbon red hot and quench it in water. This makes it brittle. Magnetize it as above and mark the poles. Break it in halves, quarters, eighths, &c. And show that each fragment is a perfect magnet and has as strong polarity as the original.

73. Put a soft iron bar (a tenpenny nail) with one end in contact with one pole of the horseshoe magnet and show that the further end has the same polarity as the pole touched.

Coercive Force.

74. Compare the rate of magnetization of the iron bar in 73 with that of a hardened steel ribbon.

Induction.

75. Hang a number of iron wires of equal length from one pole of a magnet and observe how the other ends repel one another.

76. Hang by a silk fibre a soft iron nail horizontally over the poles of a horseshoe magnet standing on its bend in a vertical plane. Bring pole of another magnet near one end of nail, and obtain repulsion if the pole of the moveable magnet is of the opposite kind to that of the fixed one.

Relation of Heat to Magnetism.

77. Heat red hot an iron ball in the fire, and show that it is not attracted by a magnet. Heat a magnet, 72, red hot and show that it loses its magnetism.

Magnetic Curves.

78. Place the horseshoe magnet without its keeper beneath a sheet of cardboard. Scatter iron filings on the card; observe the lines traced out by the filings; show that each particle, being an induced magnet, arranges itself according to the fact that repulsion and

attraction vary inversely with the square of the distance. Repeat the experiments with one bar magnet, also with two (*a*) put with like poles in the same direction, and (*b*) with unlike poles in the same direction.

Dip.

79. Fasten firmly with hot shellac a silk fibre to the middle of a piece of unmagnetized knitting needle. File off one end till the needle hangs horizontally. Magnetize it, and notice the dip.

80. Hold a poker in the magnetic dip, and in the magnetic meridian, that is, parallel to the magnetic axis of the earth. Hit its upper end with a hammer and show that it becomes magnetic in such a manner that its N. seeking end is downwards, and towards the north. This shows that the magnetism at the North geographic pole is south-seeking.

SUBJECT IX.—APPARATUS AND MATERIAL FOR ELEMENTARY EXPERIMENTS IN ELECTRICITY AND MAGNETISM.

1. Three square feet of flannel. Some skin with fur.
2. A piece of resin.
3. A light lath four feet long.
4. Sheets of brown paper.
5. Clothes brush.
6. Thin writing paper (foreign post).
7. Bottle caoutchouc.
8. Collodion.
9. Six squares, each six inches square, of best black silk, sewn together at the edges like a kettle holder.
10. Melt half an ounce of tin in Hessian crucible (L. A. 3), add one ounce of zinc, and just melt, add four ounces of mercury. Stir while cooling (electrical amalgam). Wash lard in hot water to remove salt; dry and rub up with above amalgam; using as little lard as possible. Keep bottled.
11. A book of gold leaf or best "Dutch metal."
12. A square foot mahogany board.
13. 3 lbs. shellac.
14. A yard of white pure silk ribbon.
15. Some collodion, that is gun-cotton dissolved in ether and alcohol (equal parts). Spread some on plate and let dry.
16. Vulcanized caoutchouc tubing $\frac{1}{2}$ inch bore. (See also S. A. 26.)
17. Melt or soften 1 lb. of shellac, and mould it into a stick about 8 inches long; roll it between cold surfaces to smooth it.
18. Three square feet vulcanized sheet caoutchouc as thick as possible.
19. Make stirrups of wire for holding rods of substances for suspension.
20. Cork up one end of a glass tube. Melt stick of sulphur (L. A. 3). Pour into tube, allow to cool and push out.
21. Two or three sticks of sealing wax.

22. *Electroscope.*—Fit a cork into a narrow-necked 2 lb. flat-bottomed flask. Bore a hole $\frac{1}{2}$ inch diameter through cork. Bore a hole through the edge of a penny piece. Solder a piece of stout brass wire 8 inches long to middle of coin perpendicular to its plane. Pass other end through cork. Warm wire and coat so thickly with shellac where the wire passes through the cork that the hole is quite filled up, the wire in the centre, the surfaces of the shellac quite smooth and the lower end of the wire reaching to the beginning of the neck of the flask. Cut a strip of tinplate 1 inch long and $\frac{1}{4}$ inch wide. Solder it on to the bottom of the wire at right angles to the wire, and in a vertical plane. File the lower edge sharp and perfectly straight. Moisten both sides of the tinplate with a very little thin gum. Cut between paper with sharp scissors two strips of gold leaf or Dutch metal $\frac{3}{4}$ inch wide and as long as the leaf. Lay the gummed faces upon the leaf squarely so that one is on each side. Fit cork with wire, &c. in bottle.

23. 1 oz. gun cotton.

24. 10 yards fine copper wire.

25. Make shellac varnish. Cover shellac for 24 hours with its own weight of alcohol (methylated spirit); dilute with two or three times as much spirit. Strain through flannel, keep bottled. Articles to be varnished should be previously heated, and the varnish applied while they are hot.

26. Two wooden balls 4 inches diam. covered with tin foil on varnished glass tube supports, on stands, so arranged that the balls may be made to rest in contact. Smooth wire eyes on the top of the balls.

27. A cylinder or plate "electrical machine," preferably the former, with both conductors isolated.

28. Discharging tongs. A piece of gutta percha covered copper wire about 2 feet long, with leaden bullets fused on to the ends. This is bent in the middle like a pair of sugar tongs. *See* N.B. 41.

29. Electric jar (Leyden jar). Paste tin foil on thick wide-mouthed glass jar inside and out, leaving 2 inches free from the top. Varnish the uncovered lip both inside and out. Fit cork or wooden cover to the jar. Through the cover pass a stiff metal wire bearing a knob above and a chain or elastic wire spring below, which always rests upon the inner coating. Make six such jars.

30. Fasten to prime (+) conductor a wire upright with a knob on the top. Hang from the top of the wire by a cotton thread a pith ball, which rests against the wire. This is used when jars are to be charged. (Electric gauge.)

31. 1 oz. gunpowder.

32. Starch, iodide of potassium, red lead, muslin.

33. Two iron balls, about 4 lbs. weight, with iron eyes. A long iron hook. A short iron hook fastened to an isolating handle.

Voltaic Electricity.

34. *Set up Platino-Zinc Battery.* — Amalgamate zinc plates by rubbing on them with a rag at the end of a stick dilute sulphuric acid and mercury. The outer glazed cells are $\frac{4}{5}$ths filled with dilute sulphuric acid (1 of vitriol to 12 of water). The zincs are placed in these. The inner porous cells are nearly filled with the strongest nitric acid. The platinums are placed in them. The cells are

placed side by side and the zinc of one cell is clamped to the platinum of the next, and so on. The last cell may be left empty of sulphuric acid, but the zinc retained to support the platinum. Copper wires are fastened to the two terminal metals. These wires may each be four feet long.

35. Six yards "covered" copper wire, *i.e.*, spun over with cotton.

36. A horseshoe permanent magnet about 4 inches long with keeper.

37. A yard of steel ribbon (clock spring).

38. *Cell for Electrolysing Water.*—Cut off short the neck of a funnel. Solder two strips of platinum foil 2 inches × $\frac{1}{2}$ inch to two copper wires. Pass the wires through two holes in a cork in the neck of the funnel. Fill up with melted paraffin until the points of soldering are covered; the foils are parallel to one another, facing one another about one inch apart. The funnel is supported on a filter stand.

LONDON:
Printed by GEORGE E. EYRE and WILLIAM SPOTTISWOODE,
Printers to the Queen's most Excellent Majesty.
For Her Majesty's Stationery Office.
[20036.—1000.—3/81.]